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The Extension of the Card-Sorting Method to War-time Problems in Timber Identification

By H. E. Dadswell, D.Sc., Audrey M. Eckersley, M.Sc.,* Florence V. Griffin,*
and H. D. Ingle, B.For.Sc.**

Summary.

The war-time activities of the Division of Forest Products with respect to the development of simple means for the identification of the timbers in the various Pacific operational areas have been described.

For the benefit of other workers in this field a detailed description has been given of (a) the first sample card-sorting key developed for the identification of timbers of the South-West Pacific area, and (b) the modified and finally adopted card-sorting key for New Guinea timbers.

Reference has also been made to the development of similar keys for (a) the timbers of the Philippines, and (b) the timbers of Malaya and the East Indies.

Various factors in this type of identification key have been discussed and reference made to its value for field identification.

I. Introduction

For some time after the outbreak of hostilities in the Pacific little or no attention was given to timber identification problems. Then, suddenly it was realized by everyone that timber, because of its universal usefulness, was still a most valuable munition of war. This being so, it was often essential to know the identity of the various timbers being used, so that their use could be to the best advantage. While the problem was not particularly serious when bases were being built in Australia, mainly because the properties and identity of the more common Australian timbers were fairly well known, it did become serious when large bases were built in the islands to the north of Australia where local timbers had to be used because of the lack of sufficient shipping to bring timber from Australia or from North America. It was at this stage that the Division of Forest Products was asked to assist in (a) providing information regarding the properties and uses of all island timbers and (b) suggesting methods by means of which such timbers could be identified as accurately as possible by the personnel of appropriate units in the various Services. It was immediately obvious that these demands could probably be met satisfactorily by the development of some simple type of

* An officer of the Division of Forest Products.

one region, and consideration was therefore given to the possibilities of a key of the card-sorting type which would have the added advantage that information regarding any particular timber could be included on the card for that timber.

The application of the card-sorting principle to timber identification problems had been well established as early as 1936, and has been used in various laboratories where timber identification is carried out. Clarke (1938) published details of a perforated card key for identification key covering the more important timber species of any hardwood timbers, and Phillips (1941) described a similar type of key for the identification of coniferous timbers. The principle was further extended by Dadswell and Eckersley (1941) to a rather more specialized problem, namely the identification of the various timber species of the genus *Eucalyptus*. In all these keys, however, the emphasis has been on identification in the laboratory, where examination of details of wood anatomy can be completed at leisure, using thin sections and the microscope. The Forest Products Laboratory, Princes Risborough, England, had, however, proposed a card-sorting key based on the use of the hand lens only and details were set out in a Progress Report which the authors have had the privilege of consulting.

The Section of Wood Structure of the Division of Forest Products has since 1936 employed the card-sorting method for identification purposes; two systems, one for hardwoods and the other for coniferous woods, were developed, in addition to the specialized key for the eucalypt timbers previously referred to. These have proved their value many times over and duplicate sets have been forwarded to the Australian Forestry School, Canberra, and the various State Forest Services. Again, however, these keys were designed for laboratory use by wood anatomists, and, invaluable as they are, they are not the type for field use by operators with little or no knowledge of wood anatomy. The problem therefore was the development of a simple card-sorting key using macroscopic features only, so that any one without specialized training in wood technology could operate it. The latter point was essential because it was visualized that such a key would be used by engineer and forestry units in both the Australian and American Armies.

In as much as New Guinea was for some time the centre of action for the Pacific war, the first attempt at the development of a simple card-sorting key was made using a number of the more important New Guinea timbers. Information on these timbers was obtained from examination of available material of the species selected (50 in all), many of which occur in other areas of the South-West Pacific as well as New Guinea. Thus it was fortunate that the Division had in its possession collections of various timbers from New Guinea, the Dutch East Indies, Malaya, and the Philippines. In addition some authentic material was available from New Guinea, and Mr. C. E. Lane-Poole, then Inspector-General of Forests, made available pieces of timber collected by him during his survey of New Guinea (Lane-Poole, 1925). This first key, described in some detail below, was perhaps over-simplified in that it was based on macroscopic features visible to the naked eye only (i.e. a hand lens was neither an essential

nor a desirable aid). The cards for the 50 selected New Guinea timbers, each suitably notched at the perforations corresponding to the features observed for each species, together with various supplementary sheets of instructions, definitions, &c., were issued in a suitably prepared cardboard container. A number of such sets were despatched to Australian and American Army Units—mainly Engineers. The key proved very successful even when used by untrained personnel. However, with the transfer to New Guinea of various Australian Forestry Units and as a result of further work, it was felt that a larger, more detailed key should be developed. In this second key more timbers were included and a wider range of features employed, including those visible with a hand lens, for it was considered that the personnel of forestry units would have sufficient training to use a hand lens key of this type (described in detail below). In addition, arrangements were made by the Australian Army through the Engineer-in-Chief for one of us (H.E.D.) to visit forward areas to give instructions on the correct methods of using the key. It was indeed surprising how rapidly persons unacquainted with wood technology mastered the procedure of identification by this means and how effectively they could use the key. While in New Guinea with the Australian Army Unit, New Guinea Forests, additional material of the various more or less known commercial timbers and of other species with potential commercial value was collected. Examination of this material indicated the need for modifications and additions, and eventually the key for the timbers of New Guinea and neighbouring islands covered some 140 different species. As a result of the demand for information on uses and properties of each of these, provision was made on the cards for strength grouping, durability classes, and possible uses.

Concurrently with the extension of the key for timbers of the South-West Pacific area, the Division was busily engaged in the preparation of a similar type of key for the commercial timbers of the Philippines. The request for 300 sets of such a key was received through the Allied Geographical Section of the South-West Pacific Command, who demanded 150 of these keys before the invasion of the Philippines. This demand was met, even though it was requested that the card for each species include botanical information and where possible illustrations of botanical features. Again the cards were adapted so that sortings could be made on properties and uses as well as on anatomical features. Most of the information on the timbers was gathered from the publication on "Philippine Woods" by Luis Reyes (1938); other information was gained from the examination of available timber specimens.

The next request came from the Australian Army, and card-sorting keys covering timbers of Borneo were urgently required. Because many of the important timbers of this region were also common in the other islands of the East Indies and in the Malay Peninsula, a comprehensive key covering timbers (117 in all) of Borneo, Java, Sumatra, Malaya, and Burma was developed following the lines adopted in the case of the Philippine timbers. Before the invasion of Borneo 100 sets were prepared and 25 forwarded to the Australian Army through the Engineer-in-Chief's Branch. Sixty sets were sent to the South-East Asia Command through the Allied Geographical

Section, South-West Pacific Command. Once again botanical information on the various species was included, together with information on the properties and uses of the timbers.

Special card-sorting identification keys covering (a) timbers of Northern Territory and (b) Australian and Island timbers used for marine piling, were also developed for use by Australian Army personnel. In all, in less than twelve months, over 60,000 individual cards were prepared and, as most of the work on notching, affixing photographs, &c., was done by hand, it will be appreciated that a considerable effort was involved.

2. Description of the First Identification Key for Timbers of the South-West Pacific

The cards adopted for this first key were 5 in. by 4 in. in size with perforations along both 5 in. sides. Forty of these perforations were available and of these, 39 were allotted to the possible variations in macroscopic features as shown in Fig. 1 and as listed below. The features were selected so as to give a fairly wide range of variation in weight, colour, pore size, and arrangement, vessel contents, rays, and soft tissue; in addition perforations were allotted to locality and topography. For every timber included the descriptions and notchings for positive features were based on the macroscopic examination of

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NEW GUINEA	NEW BRITAIN, ETC.	DUTCH EAST INDIES	PHILIPPINES	HIGHLANDS	FOOTHILLS	COASTAL	FLOATS EASILY	BARELY FLOATS	SINKS	WHITE, PALE YELLOW, PALE BROWN	PINK, RED	OTHER COLOURS	ODOUR	FROTTHING	VERTICAL CANALS	RAY FIG. CONSP.	RIPPLE MARKS	HARD TO CUT ACROSS GRAIN	VERY SOFT TO CUT ACROSS GRAIN
LOCATION				TOPOGRAPHY			WEIGHT		COLOUR			OTHER FEATURES							

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SPECIES *Anisoptera polyandra*.

KNOWN NATIVE NAMES garawa (Buna), karawa (Binandele) karalaka (Vailala).

PORE SIZE					ARRANGEMENT & CONTENTS							SOFT TISSUE.					RAYS					
21	22	23	24		25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40		
LARGE	VERY SMALL	INDISTINCT TO NAKED EYE	INTERMEDIATE	JUST VISIBLE TO NAKED EYE	ABSENT	SOLITARY	OBLIQUE	TANGENTIAL	RADIAL	CLUSTERS	RING POROUS	CONTENTS CONSP	NOT VISIBLE TO NAKED EYE	WIDER THAN PORES	REGULAR BANDS	NARROWER THAN PORES	IRREGULAR BANDS	WING LIKE	SURROUNDING PORES	EQUAL TO, OR WIDER THAN PORES	NARROWER THAN PORES	

FIG. 1.—Face view of card used in the first card sorting key for timbers of the South-West Pacific Area—macroscopic features used only.

numerous specimens of the wood (without use of hand lens). Thus the pore size and arrangement recorded were based on the examination of a cleanly cut cross section, as was the description of soft tissue and rays. On the front of the card the botanical name of the timber was typed together with known native names and/or the name by which the timber is commonly known. On the back of the card for each species was pasted a photograph of the cleanly cut end section of the wood taken at approximately three magnifications; this gave a very good picture of the arrangement and size of pores, soft tissue and rays. Also on the back of the card, details of the timber, its colour, density, durability, uses, and special properties were given (see Fig. 2). For the benefit of those untrained in wood technology and lacking knowledge of the various terms used, a number of definitions were included with the prepared cards together with detailed notes on how to use the key and explanations of the reasons for using various features. Further, a photographic print of a series of diagrams illustrating various structural features was prepared and issued with each batch of cards.



Remarks: Wood pale yellowish brown. Vertical canals shew white deposits & may be in concentric bands or scattered among pores. Timber useful for building construction (scantling). A.D. density approx. 40 lb./cu.ft.

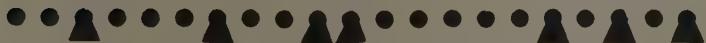


FIG. 2.—Back of card shown in Fig. 1.

It has been considered desirable in this brief review of the work to include some reference to the various features used, and to the underlying reasons for the choice of these features. This information may prove of value to other workers desirous of developing identification keys of this type. The details are set out below:—

General Heading.	Feature Number.	Feature Description.	Remarks.
Location	1	New Guinea	Some indication of the known distribution of each species is valuable
	2	New Britain and neighbouring islands ..	
	3	Dutch East Indies ..	
	4	Philippines	
Topography	5	Highlands	Areas over 4,000 feet above sea level
	6	Foothills	Areas from 1,000 to 4,000 feet above sea level
	7	Coastal	Areas up to 1,000 feet above sea level
Weight	8	Floats easily	There are difficulties in assessing the density of any timber especially in the green state, hence the three suggested weight variations
	9	Barely floats	
	10	Sinks	
Colour	11	White, pale brown, pale yellow ..	Classification on a colour basis is not easy; therefore two main groupings were used to cover the pale timbers and the red timbers. Under other colours it was intended to include bright yellow, dark brown, chocolate, and any variegated colours
	12	Pink, red	
	13	Other colours ..	
Others features ..	14	Odour	Many timbers have a characteristic odour
	15	Frothing test positive ..	This refers to the fact that shavings from some timbers froth when shaken with water
	16	Vertical canals ..	Designed to cover the canals of the Dipterocarpaceae as well as the anomalous type observed in some other species
	17	Ray figure conspicuous	Many timbers have a conspicuous ray figure or ray fleck on split or sawn radial surfaces
	18	Ripple marks ..	Storied structure as seen on a freshly cut tangential surface

General Heading.	Feature Number.	Feature Description.	Remarks.
Others features— <i>continued</i> .	19	Hard to cut across grain	{ Test carried out with pocket knife; designed to pick out the very hard and the very soft timbers
	20	Very soft to cut across grain	
Pore size (appearance in cross-section)	21	Large	Readily seen with naked eye
	22	Very small	Indistinct or invisible to naked eye
	23	Intermediate in size ..	Just visible to naked eye
	24	Absent	To cover all coniferous timbers
Pore arrangement and contents (appearance in cross-section)	25	Solitary	More than 75 per cent. solitary as in various eucalypts
	26	Oblique chains	
	27	Tangential arrangement	As in members of the Proteaceae
	28	Radial arrangement ..	The typical radial multiples
	29	Clusters	
	30	Ring-porous	
	31	Contents conspicuous ..	To cover the white or coloured contents of vessels and tyloses
Soft tissue (appearance in cross-section)	32	Not visible to naked eye	This also covered "absent"
	33	In regular* bands wider than pores	{ The width of the bands in comparison with the radial diameter of pores
	34	In regular* bands narrower than pores	
	35	In irregular* bands ..	E.g., terminal
	36	Wing-like	
	37	Surrounding pores	
Rays (appearance in cross-section)	38	Equal to or wider than pores	{ I.e., in comparison with average tangential diameter of pores
	39	Narrower than pores	

* "Regular" and "irregular" designed to cover the radial spacing of the soft tissue band

A series of simple notes was prepared for the guidance of users of this key and certain of them are of general interest, namely:—

(i) Where a red line was placed opposite the notch for any particular feature it meant that this feature was not readily discernible to the naked eye, although visible with a hand lens.

(ii) Where a black line was placed opposite the notch for any particular feature it meant that the feature was not common for the timber in question.

(iii) Stress was laid on the desirability of sorting on the most obvious features first, with no reference to the order of appearance on the cards—doubtful features to be left or considered only at the end.

(iv) Only a limited number of the most important timbers (50) were included in the key; in any area other timbers not included in the key might be encountered.

(v) Details of structure are more clearly revealed if the cleanly-cut cross-sectional surface is moistened with water.

(vi) In a macroscopic key of this nature it is rare for only one card to remain after a number of sortings. When several cards remain reference should be made to the photographs pasted on the backs of each card and to the details of colour and properties given thereon as a guide to final identification.

With the above information it should be possible to use the key effectively for those timbers covered by it. This was proved in the laboratory where untrained juniors using the key made a high percentage of correct identifications, and in the field where in many cases quite untrained operators effected satisfactory identifications. However, as intimated earlier, it was soon felt that the card-sorting type of key would be much more effective if more species were covered and if use was made of a hand lens in the examination of the wood.

3. Description of the Enlarged and Modified Identification Key for Timbers of New Guinea and Neighbouring Islands

In this key the size of the card was increased to $6\frac{3}{4}$ in. by $4\frac{9}{16}$ in. and it was perforated on all edges. On the face of the card there were 60 perforations available for use, as shown in Fig. 3. In the later models twenty spare perforations on the narrow edges were utilized for strength groupings, durability classes and uses, as shown in Fig. 4, by using the back of the card. Thus a total of 80 perforations was available for notching if and when required. It will be seen that from the identification angle 21 additional perforations were available for coding to possible variations in macroscopic features in comparison with the first card sorting set described above. More attention was given to variations in colour, weight, hardness, and because of the greater detail visible with the hand lens, more variations in ray structure, soft tissue, and pore size and arrangement were utilized. The final form of the cards for this key was not completed until early 1946, but by June, 1944, the first sets, with the 60 possible variations as shown in Fig. 1, were forwarded to operational areas. Subsequent modifications were mainly concerned with:—

- (a) The addition of information on the strength groupings, durability classes, and uses as mentioned above.
- (c) The addition of new species which has increased the present size of the set to a total of 137 species.

(b) Revision of the species investigated earlier as a result of additional material becoming available for examination.

On the back of each card was pasted a low-power ($3\times$) photograph of the cross-section of the timber described. The cards were issued in a suitable container (first sets cardboard, later wood) and were accompanied by a colour chart for assistance in matching colours, a booklet of explanatory notes, a photographic copy of illustrations of various characteristic anatomical features, and a needle for sorting purposes.

36	FEW	NUMBER	SIZE	PORES	ARRANGEMENT	WEIGHT	HARDNESS	31	NEW GUINEA AND NEIGHBOURING ISLANDS	LOCALITY	COLOUR	1	WHITISH, PALE BROWN, PALE YELLOW, STRAW	OTHER FEATURES	26	MALAYA	NEW GUINEA SPECIES IDENTIFICATION CARD USING MACROSCOPIC FEATURES VISIBLE WITH AID OF A HAND LENS.	TOPOGRAPHY	OTHER FEATURES	20	A DEFINITE ODOUR
37	MODERATELY NUMEROUS							2	DARK BROWN			21	FROTHING TEST POSITIVE								
38	VERY NUMEROUS							3	PINK OR RED TINTS INCLUD. RED BROWN			22	RIPPLE MARKS								
39	LARGE							4	OTHER COLOURS—BLACK, PURPLE, BRIGHT YELLOW, ETC.			23	VERTICAL CANALS CONCENTRIC								
40	INTERMEDIATE VISIBLE TO NAKED EYE							5	MOTTLED OR STREAKY			24	DISTINCT OILINESS OR GREASINESS								
41	SMALL—INDISTINCT TO NAKED EYE	PORES	ARRANGEMENT	WEIGHT	HARDNESS	SEE BACK OF CARD FOR REMARKS. SANDS & McDONALD PTY. LTD. PARAMOUNT NO. 3889	Anisoptera polyandra Bl. Dipterocarpaceae.	32	CELEBES, TIMOR, MOLUCCAS	LOCALITY	COLOUR	6	BROAD & CONSPICUOUS ON CROSS SECTION	OTHER FEATURES	27	PHILIPPINES	NEW GUINEA SPECIES IDENTIFICATION CARD USING MACROSCOPIC FEATURES VISIBLE WITH AID OF A HAND LENS.	TOPOGRAPHY	OTHER FEATURES	25	
42	VERY SMALL—BARELY VISIBLE WITH LENS											7	AS WIDE OR WIDER THAN PORES		28	BORNEO, JAVA, SUMATRA				25	
43	ABSENT											8	NARROWER THAN PORES		29					25	
44	RING POROUS OR SEMI-RING POROUS											9	NOT CLEARLY VISIBLE EVEN WITH LENS		30					25	
45	PREDOMINANTLY SOLITARY											10	CONSPIC. ON RADIAL SURFACE DUE TO COLOUR		30					25	
46	RADIAL MULTIPLES—UP TO AND INCLUD. 4											11	WITH GUM CANALS		30					25	
47	RADIAL MULTIPLES OF MORE THAN 4											12	ABSENT		30					25	
48	OBLIQUE											13	IN REGULAR BANDS WIDER THAN PORES		30					25	
49	TANGENTIAL											14	IN REGULAR BANDS NARROWER THAN PORES		30					25	
50	CLUSTERS											15	IN IRREGULARLY SPACED BANDS		30					25	
51	TYLOSES COMMON	16	SURROUNDING PORES	30		25															
52	WHITE OR YELLOW DEPOSITS COMMON	17	WING-LIKE CONFLUENT	30		25															
53	VERY HEAVY	18	DIFFUSE	30		25															
54	HEAVY MOD. HEAVY	19	RETICULATE	30		25															
55	LIGHT—MOD. LIGHT	20	A DEFINITE ODOUR	30		25															
56	VERY LIGHT	21	FROTHING TEST POSITIVE	30		25															
57	VERY HARD HORNY TO CUT	22	RIPPLE MARKS	30		25															
58	HARD TO CUT	23	VERTICAL CANALS CONCENTRIC	30		25															
59	INTERMEDIATE	24	DISTINCT OILINESS OR GREASINESS	30		25															
60	VERY SOFT TO CUT ACROSS GRAIN	25		30		25															

FIG. 3.—Face view of card finally adopted for use in card sorting key for New Guinea timbers. Macroscopic features visible with hand lens used.

It was suggested that a piece of timber to be identified should be prepared and examined according to the following procedure:—

- (a) Make a clean cut on the cross-section using a very sharp knife or razor blade.
- (b) Examine the cleanly cut cross-section using a hand lens, noting direction and size of rays; number, size, arrangement, and contents of pores; arrangements of soft tissue.
- (c) Split along true radial and tangential surfaces and clean up the tangential surface with a knife or a razor blade.
- (d) Examine radial surface for marked difference in colour between rays and background.
- (e) Examine tangential surface for ripple marks and presence of gum canals.
- (f) Note colour, impression of hardness by cutting across grain, and approximate density, remembering that hardness and density are affected by moisture content.
- (g) Keep a look out for other features, such as definite odour, distinct oiliness, or greasiness; or stickiness, presence of concentric vertical canals, and ability of shavings to produce froth when shaken with water.

The anatomical features and physical properties used were similar to, but did not exactly follow, those given above in the description of the first macroscopic key. They are listed below with explanatory remarks:—

Colour.

It was considered of advantage to widen the colour groupings and, as colour classification can be very difficult, a colour chart was provided so that the operator might assess the colour of dry longitudinal surfaces of the specimens under examination. It was pointed out that colour will vary considerably depending on (a) moisture content, (b) sapwood or truewood, (c) age of tree from which specimen has been taken, (d) age of specimen, (e) the surface examined, (f) presence of decay or sap stain.

1. Whitish, pale-brown, pale-yellow, straw.
2. Dark-brown (a definite brown).
3. Pink or red tints, including red-brown.
4. Other colours, e.g. black, purple, orange, bright-yellow, &c.
5. Mottled or streaky.

i.e. any colour not specified under 1, 2, or 3.

Rays.

In this key there were no codings for heterogeneity or homogeneity, although with the hand lens it is often easy to pick on the upright ray cells and to detect oil cells on a split radial face. Reference to these, however, was usually made on the back of the cards.

6. Broad and conspicuous on cross-section
 7. As wide or wider than pores
 8. Narrower than pores
 9. Not clearly visible even with lens
 10. Conspicuous on radial surface owing to colour
 11. With gum canals

Self explanatory, similar to oak or the silky oaks.
 Width of ray estimated by comparison with tangential diameter of pores—a useful feature as proved from first set.
 In some cases rays are too narrow or not of sufficient contrast to be seen on cross-section even with a hand lens.
 This is irrespective of size and meant to refer only to colour prominence; experience showed that it was not a particularly useful feature.
 The canals appear under lens as dark cavities in rays and may be seen on freshly cut tangential surfaces or split radial surfaces. A good positive feature.

Soft Tissue (Wood Parenchyma).

The groupings in this section (soft tissue) were selected to give greatest possible assistance in sorting. In the preparation of the individual cards it was sometimes necessary to notch more than one perforation in this group to cover variation in the species or possible difficulties in interpretation. It was often particularly difficult to differentiate between “diffuse” and “reticulate.”

12. Absent
 13. In regular bands wider than pores
 14. In regular bands narrower than pores
 15. In irregularly spaced bands ..
 16. Surrounding pores
 17. Wing-like, confluent.
 18. Diffuse
 19. Reticulate

To cover species on which soft tissue is absent or difficult to see under lens.
 Regular bands are those which occur at regular intervals as seen on cross-section. Width as in earlier key.
 e.g. terminal.
 Difficult to detect even with lens.
 Cells scattered irregularly.
 In fine lines only visible with lens and forming a sort of network with the rays.

Other Features.

20. A definite odour
 21. Frothing test positive
 22. Ripple marks
 23. Vertical canals concentric
 24. Distinct oiliness or greasiness

Remarks as for first key.
 An additional feature, detected by feeling longitudinal surfaces: stickiness of the surface is also allowed for here.

25. —

Topography.

26. Highlands
 27. Foothills
 28. Coastal
 29. Swamps

As in first key.
 Additional; intended to cover mangrove swamps and other swampy areas.

Locality.

30. Australia.				
31. New Guinea and neighbouring islands				
32. Celebes, Timor, Moluccas	..	..	..	
33. Borneo, Java, Sumatra	..	..	..	
34. Philippines	..	..	..	
35. Malaya	..	..	..	

Divisions made on somewhat different lines from those followed in first key.

Pore Number.

36. Few	..	..	..	4 or less per sq.mm.
37. Moderately numerous	..	..	..	5-11 per sq.mm.
38. Very numerous	..	..	..	More than 11 per sq.mm.

The counting of the actual number of pores was accomplished by using one of the holes in the printed card (see Figs.). These holes were found to be approximately 7 sq.mm. in area and therefore the actual pore number per sq.mm. for any timber could be obtained simply by dividing by seven the number counted in the area outlined by one perforation when the card is pressed on to a cleanly cut end section of the wood. Counts should preferably be made over several different areas and the mean taken.

Pore Size.

39. Large	..	..	..	Large and separately distinct to naked eye.
40. Intermediate	..	..	..	Visible to naked eye without any strain.
41. Small	..	..	..	Indistinct to naked eye.
42. Very small	..	..	..	Indistinct even with hand lens.

Pore Arrangement (and Contents).

43. Absent	..	..	..	
44. Ring-porous or semi ring-porous				Remarks as in first key.
45. Predominantly solitary	..	..	..	
46. Radial multiples up to and including 4	..	..	..	Considered of value to have separate perforations for long radial multiples.
47. Radial multiples over 4	..	..	..	
48. Oblique	..	..	..	
49. Tangential	..	..	..	Remarks as in first key.
50. Clusters	..	..	..	
51. Tyloses common	..	..	..	A separate perforation was taken for tyloses but should be used only when they are common enough to be quite distinct.
52. White or yellow deposits common				Again a separate perforation; the difference in appearance between white deposits and tyloses have been described.

Weight.

53. Very heavy	..	..	..	Above 62.5 lb./cu.ft. air dry to approximately 17 per cent. moisture content.
54. Heavy to moderately heavy	..	..	..	50-62.5 lb./cu.ft.
55. Light to moderately light or moderately heavy	..	..	..	30-49 lb./cu.ft.
56. Very light	..	..	..	Less than 30 lb./cu.ft.

The whole weight range was included but it was considered that perforations 53 and 56 would prove the most useful.

Hardness.

This is correlated with weight, but in these keys refers mainly to the difficulty in cutting air-dry wood across grain with a pocket knife. It was thought that here again the extremes would be most useful.

57. Very hard and horny to cut.
 58. Hard to cut.
 59. Intermediate to cut.
 60. Very soft to cut.

Strength Groups (see Langlands and Thomas, 1941).

63. Group A.
 64. Group B.
 65. Group C.
 66. Group D.

The timbers were classified into four groups as is done for Australian timbers using the following average properties selected by the Section of Timber Mechanics:—

Group.	Modulus of Rupture. (lb./sq. in.)		Modulus of Elasticity. (lb./sq. in.)		Crushing Strength Parallel to the Grain. (lb./sq. in.)		Shear Strength. (lb./sq. in.)	
	Green.	12% m.c.	Green.	12% m.c.	Green.	12% m.c.	Green.	12% m.c.
A	15,000	24,000	2,400,000	3,000,000	7,500	12,000	2,000	2,500
B	12,000	20,000	2,100,000	2,600,000	6,000	10,000	1,500	1,900
C	10,000	16,000	1,700,000	2,200,000	5,000	8,000	1,200	1,600
D	7,000	12,000	1,500,000	1,900,000	3,350	6,000	800	1,100

Note.—The above figures apply to defect-free timber only. If a card is not notched at one of the above perforations either no information on strength properties is available or it falls into a class below Group D. The latter alternative would certainly be the case with very low density timbers.

Durability Classes (Truewood only).

68. Class 1.
 69. Class 2.
 70. Class 3.
 71. Class 4.

Class 1 was meant to cover species which when used in exposed situations were highly durable, while class 4 covered those of low durability. This classification was designed to refer to attack by fungi and termites only, and not to resistance to mechanical wear, or to attack by marine organisms. The placing of the various species in these classes was somewhat uncertain because of the lack of detailed knowledge. However, it is a general indication.

Uses. Features 74-85 inclusive See Fig. 4 for details.

The inclusion of information on strength, durability and uses rendered the sets more generally useful, as the card for each species can be considered as giving the available information on properties,

uses, and structure for that species. The latest model of this key has definite post-war application and a number of sets have already been distributed.

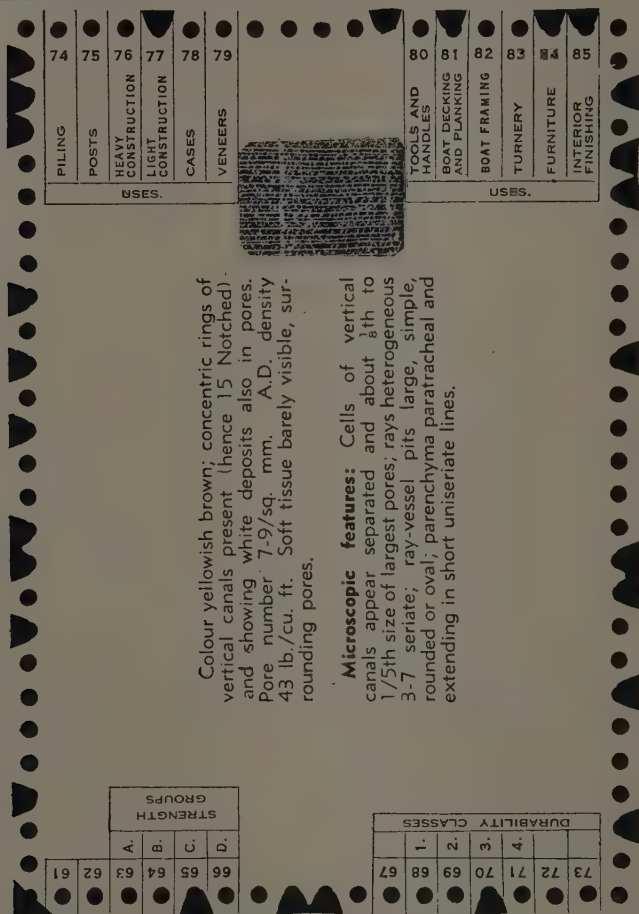


FIG. 4.—Back view of card shown in Fig. 3.

4. The Card-Sorting Key for Timbers of the Philippine Islands

This key was in essence identical with that prepared for the New Guinea timbers and described in detail in section 3 above. However, there were certain modifications and additions. On the face of each card was printed the specific name and common name of the timber, while on the back of the card there was affixed an annotated photograph of a cross-section of the timber magnified approximately three times together with a brief timber description, notes on the size and

type of tree, botanical characteristics in simplified terms (see Fig. 5), information on the occurrence of the species in the Philippines. In addition, where available, a line drawing of leaves, flowers, and fruit was included. Many of these diagrams were obtained through the courtesy of the National Herbarium, Melbourne. They were prepared from photographic copies of illustrations or from photographs of herbarium material. The details in such photographs were outlined with indian ink and the unwanted portions bleached out leaving suitable line drawings from which the blocks were made.

74	PILING	USES.	OCCURRENCE. Widely distributed throughout Philippines from Batanes to Mindanao and Palawan. Common in forests, usually along streams.	Soft tissue around pores and in irregularly spaced bands. Pores chiefly in radial multiples; 3-6/sq. mm. White deposits in pores.	BOTANICAL NOTES. TREE large with trunk 70-90' long and diameter up to 3'; heavily buttressed. BARK scaly red-brown, scaling in small pieces leaving bark more or less smooth, $\frac{3}{8}$" thick. LEAVES red when young, compound, with stalk up to 18" long. Leaflets 2-7" long by $3-2\frac{1}{2}$" wide, lance-shaped, smooth except for midrib and lateral veins which bear hairs, edges shallowly toothed. FLOWERS in clusters 6-9" long. FRUIT apple-shaped, red and green in colour, generally single but may occur in pairs.
75	POSTS				
76	HEAVY CONSTRUCTION				
77	LIGHT CONSTRUCTION				
78	CASES				
79	VENEERS				
80	TOOLS AND HANDLES	USES.	TIMBER DESCRIPTION. Truewood light pinkish-brown to bright red-brown or brown, sapwood 1-2" wide, not distinct. A.D. density = 40-45 lb./cu. ft. Green density = 66 lb./cu. ft.		
81	BOAT DECKING AND PLANKING				
82	BOAT FRAMING				
83	TURNERY				
84	FURNITURE				
85	INTERIOR FINISHING				





STRENGTH GROUPS.			
A.	B.	C.	D.
61	62	63	64
65	66	67	

DURABILITY CLASSES.			
TERMITTE RESISTANCE		EXPOSED POSITIONS	
1.	2.	1.	2.
68	69	70	71
72	73	74	75

FIG. 5.—Back view of card adopted for use in card-sorting key for Philippine timbers.

Most of the information on the timbers was obtained from "Philippine Woods" by Luis Reyes and this covered the strength groupings, durability classes, and uses. For the first of these, the

data given by Reyes were used to place the various timbers in the strength groups employed by this Division and set out in detail above. For the durability classes Reyes's information was transposed directly and this meant using perforations 67-73 inclusive and subdividing as follows:—

Termite Resistance Indoors.

67. Reyes's class 1	..	..	Very resistant.
68. Reyes's class 2	..	..	Resistant to moderately resistant.
69. Reyes's class 3	..	..	Susceptible.

Durability Exposed Positions.

70. Reyes's class 1	..	..	Very durable—lasting over nine years.
71. Reyes's class 2	..	..	Durable—lasting 4½-9 years.
72. Reyes's class 3	..	..	Moderately durable—lasting 2½-4½ years.
73. Reyes's class 4 and 5	..	..	Perishable—lasting less than 2½ years.

It will be noted that these classifications are somewhat different from those employed for the New Guinea timbers but as it was intended that the cards be used in the Philippines it was considered desirable to retain the durability classes developed there.

Again the cards were accompanied by colour chart, booklet of instructions and explanatory notes, illustrations of various anatomical features, and a needle for sorting. All were housed in a neat wooden box with sliding lid.

5. The Card-Sorting Key for Timbers of Burma, Malaya, and the East Indies

The cards in this key were similar to those used for the Philippine timbers. The botanical and common name of each timber was printed on the face of the card for that timber while on the reverse side the illustrations of botanical features, botanical notes, timber description, and photograph of the cross-section of the wood were again included. Perforations were allotted to strength groups, durability classes, and uses as in the card for New Guinea timbers illustrated in Fig. 4. The information on the botanical side was obtained through the kind co-operation of the Director of the National Herbarium, Melbourne, and the Government Botanist, Brisbane, and his staff.

The information on the timbers of the various localities covered was obtained both from examination of authentic material from these localities and from published information on the various species selected for inclusion. The actual number of timbers (117) naturally does not cover to any extent the species occurring in these regions. They were selected for inclusion on the basis of properties, occurrence, and likelihood of use by Army engineers.

6. General

In the two other special keys prepared (referred to in the Introduction) the same type of card was used as for the final modified New Guinea set. Six sets were prepared of the key for the Northern Territory timbers and a total of 40 species covered. These sets were used by the Australian Army Forestry and Engineer Units in that area. Only two sets of the special key covering Australian and New

Guinea timbers suitable for marine piling were prepared. Forty-two species were covered. This key was used by Major A. W. Shillinglaw of the Engineer-in-Chief's Branch of the Australian Army in a special survey of piling carried out in the New Guinea operational zone (Shillinglaw and Moore, 1945).

In war-time it is, of course, difficult to find out just how effective something of this nature has been. The cards definitely proved effective in New Guinea but this may have been due to the fact that they were mainly used by forestry units, to the personnel of which a certain degree of instruction had been given. No reports were received regarding the Philippine card sets, although from time to time the Division of Forest Products has received letters from individuals in U.S.A., the Philippines, and the Hawaiian Islands who have referred to the key and have mentioned its value. Regarding the key for Malayan and East Indies timbers, again no very definite information is available. It did prove useful in Borneo where it was handled by officers of the Australian Army who had previously been trained on New Guinea timbers, but the war ended before it could be proved in Malaya.

However, the development of such card-sorting keys for field work under difficult conditions has been supported by Desch, who has recently (1946) referred to the war work of the Division of Forest Products in the field of timber identifications. Normand (1946) has similarly shown his interest and has made use of various features employed by us in order to develop a simple card-sorting key for French colonial timbers.

The fact that virtually untrained operators could, after short courses of instruction, carry out identifications with this type of key led to the consideration of the development of such a key for Australian commercial timbers and this project is now in hand. Preliminary indications are that by means of such a key the identification of these timbers will be within the reach of all foresters, forestry students, and timber users.

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The Variation of Tensile Strength and Modulus of Elasticity of Hoop Pine Veneer with the Direction of the Grain

By R. S. T. Kingston, B.Sc., B.E.*

Summary.

Hoop pine veneer was tested in tension at various angles to the grain, the maximum tensile strength and the modulus of elasticity being determined.

Curves are included showing the variation of each property with the direction of the grain. These have been compared with a theoretical curve based on the assumption that wood is an orthotropic material in the case of modulus of elasticity and with a curve computed from the Hankinson formula in the case of maximum tensile strength.

For neither elastic modulus nor maximum tensile strength did the experimental points differ significantly from the computed curve.

1. Introduction

This investigation was designed to determine the effect of the angle between the direction of loading and the direction of the grain of veneer on its tensile strength and elastic modulus, and, using these data, to see how closely theoretical prediction of the tensile strength and elastic modulus in any given direction, based on measurements parallel and perpendicular to the grain, agreed with the experimental values.

Hoop pine veneer was used for the experiment. Thomas (8) found that there was no significant difference between the values for single veneer and two and three plies bonded together. Thus two or three ply material with the grain of all veneers in the same direction could have been used. One, two, and three veneers were all used in trials but, as it was found that single veneer could, with the exercise of a certain amount of care, be handled without damage, this was adopted.

2. Selection of Material, &c.

Material was selected from ten trees of hoop pine (*Araucaria cunninghamii* Ait.), one sheet of veneer being taken from each tree at random distances from the pith, all being 0.08 in. thick. The nominal test angles adopted were 0° , $5\frac{1}{2}^\circ$, $11\frac{1}{4}^\circ$, $22\frac{1}{2}^\circ$, 45° , $67\frac{1}{2}^\circ$, and 90° . The sheets were marked in such a way that four test specimens were available from each sheet for each direction less than 30° to the grain and ten specimens from each sheet at each angle greater than 30° to the grain. It was found later that the curve was insufficiently determined around the 45° point, so further specimens were cut from the spare material at angles 35° and 55° to the grain, 10 per sheet in each direction, and also 10 at 45° as controls in case there was any slight difference between widely separated parts of a sheet.

These specimens were all cut by hand with a specially sharpened knife in such a way as to minimize splitting of the veneer.

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3. Method of Test

Half of the specimens from each sheet for each angle were tested with, and the remaining half without, an extensometer attached. A Gerrard extensometer was used, its weight being carefully balanced by means of a light spring so that the load on the specimen due to the extensometer was eliminated.

Fig. 1 shows the three types of specimens used. The specimens of the first type were held in the wedge grips of the machine in the usual way and were used for specimens with angles of 0° , $5\frac{1}{2}^\circ$, and $11\frac{1}{4}^\circ$ to the grain.

Those of the second type were held by pins and were used for the $22\frac{1}{2}^\circ$, 35° , 45° , and 55° specimens, the spring balance shown in Plate 1, Fig. 1, being used for the 35° , 45° , and 55° specimens, in which cases the testing machine was not sensitive enough to read the load with sufficient accuracy, and it was necessary to use a spring balance calibrated against dead weights.

Specimens of the third type were not fitted with end pads, as these were unnecessary on account of the low load. This type was used for the $67\frac{1}{2}^\circ$ and 90° tests. In this case a special hand-operated

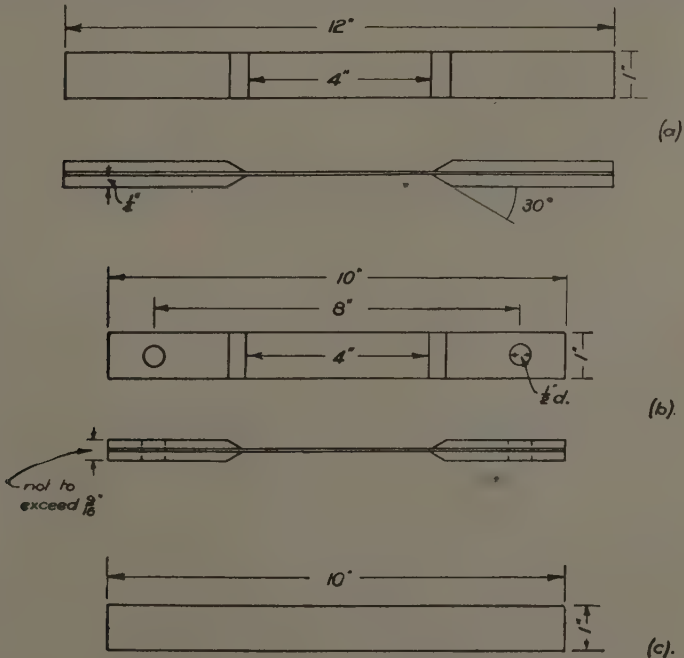


FIG. 1. (a) Test specimen with length at angles less than $22\frac{1}{2}^\circ$ to the grain. (b) Test specimens with length from $22\frac{1}{2}^\circ$ - 55° to the grain. (c) Test specimens with length at $67\frac{1}{2}^\circ$ and 90° to the grain.

machine was used, the load being determined by the deflection of a U-spring as measured by means of a dial gauge.

The material was conditioned in a room adjusted to a relative humidity which would bring the veneer to an equilibrium moisture content of 15 per cent. and was tested at a temperature of $21^{\circ}\text{C.} \pm 1^{\circ}$.

4. Results of Tests

The two groups of specimens tested at 45° to the grain showed no significant difference, so that all the results could be included without adjustment.

In Figs. 2 and 3, the maximum tensile strength and modulus of elasticity respectively have been plotted against the angle between the direction of loading and that of the grain. In each case the points plotted represent the average of all tests at each particular angle. In the case of tensile strength, results from specimens tested with an extensometer attached have been excluded on account of the possibility of damage caused by the gripping screws. In determining the average properties at each angle to the grain, specimens were culled in cases in which slight checks were present in the veneer.

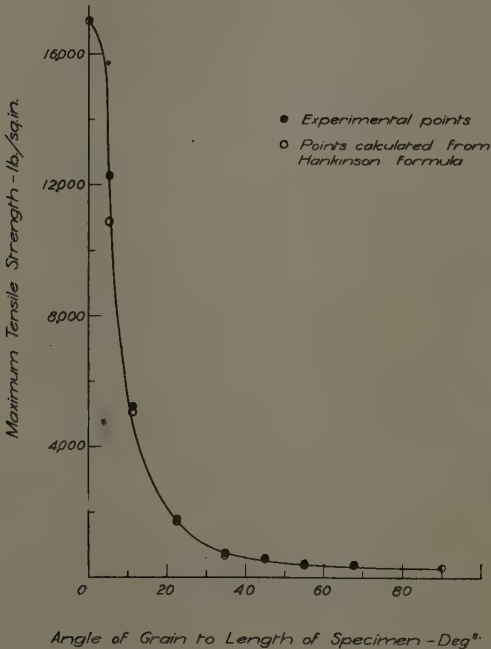


FIG. 2.—Variation in the tensile strength of hoop pine veneer with the angle between the direction of loading and the grain of the veneer.

It was especially necessary to do this carefully for tests with loading at large angles to the grain. A few very low values which may be due to variation in the tightness of peeling could not be definitely accounted for and were included in the results. Plate 1, Fig. 2, shows typical failures when the tension is parallel to the grain, and Plate 1, Fig. 3, with the tension at $5\frac{1}{2}^\circ$ to the grain. At greater angles the failures were all very similar and one of each is illustrated in Plate 1, Fig. 4.

5. Discussion of Results

In addition to the experimental values, the maximum tensile strength and modulus of elasticity, as calculated from theoretical formulae, have been plotted in Figs. 2 and 3 against the angle between the direction of loading and that of the grain.

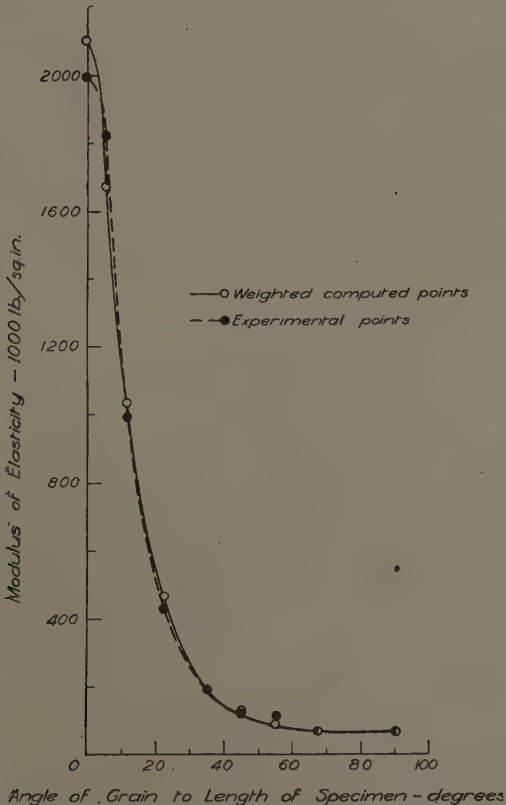


FIG. 3.—Variation in the elastic modulus of hoop pine veneer with the angle between the direction of loading and the grain of the veneer.

In the case of maximum tensile strength, the Hankinson formula has been used. This is as follows:—

$$N = \frac{PQ}{P \sin^2 \theta + Q \cos^2 \theta}$$

where N is the strength at an angle θ to the grain, P is the strength parallel to the grain, and Q is the strength perpendicular to the grain. This was put forward by Hankinson as an empirical formula and agrees very well with experimental results. This has been discussed by Langlands for wood in compression (2). He compared the Hankinson formula with others commonly used and showed that it gave, on the whole, better results than the others. He then compared it with his own experimental results and found a very close agreement. Since Langlands' paper was published, Norris (5) has shown that Hankinson's formula can be derived from Hencky's theory of failure (1, 4), by an approximate method. This places Hankinson's formula on a much more secure foundation and in view of these facts it was decided to use it here, in order to see how closely it agreed with the experimental results. It will be seen from Fig. 2 that the experimental and theoretical results do agree closely.

In the case of modulus of elasticity, assuming wood to be orthotropic, a value for the elastic modulus at any angle to the direction of the grain can be derived from the properties of the ellipsoids of stress and strain, and Hooke's law (3, 6). It is sufficient to consider the plane case only when dealing with thin sheets of peeled veneer. Roberts (7) has derived an expression which, together with Maxwell's theorem, gives the relationship used here. The result is, however, very simply derived from the basic equations for an orthotropic elastic body as given by Love (3).

Let XOY and $X'OY'$ be two sets of plane rectangular axes, the latter making an angle θ with the former. Let e_{xx} , e_{yy} , and $e_{x'x'}$, $e_{y'y'}$, be the normal strains parallel to the two sets of axes respectively whilst e_{xy} , $e_{x'y'}$, are the shear strains for these axes. Let X_x , Y_y , X'_x , Y'_y , X_y and X'_y , be the stresses in corresponding directions. Let the undashed axes be the axes of elastic symmetry of the material, the x -axis being in the longitudinal direction and the y -axis in the tangential direction. Further, let E_x and E_y be the elastic moduli in the x and y directions respectively; σ_{xy} and σ_{yx} the Poisson's ratios respectively for strain in the y direction when stress is applied in the x direction and vice versa; and μ_{xy} the modulus of rigidity for shear in the xy plane. The stress-strain relations will then be as follows:—

$$\left. \begin{aligned} e_{xx} &= \frac{1}{E_x} (X_x - \sigma_{xy} Y_y) \\ e_{yy} &= \frac{1}{E_y} (Y_y - \sigma_{yx} X_x) \\ e_{xy} &= \frac{1}{\mu_{xy}} X_y \end{aligned} \right\} \quad (I)$$

since $\frac{\sigma_{xy}}{E_x} = \frac{\sigma_{yx}}{E_y}$ by Maxwell's theorem (7).

If now we express the stresses X_x , Y_y , and X_y in terms of X'_x , Y'_y , and X'_y the following relations hold (3).

$$\left. \begin{aligned} X_x &= X'_x \cos^2\theta + Y'_y \sin^2\theta - X'_y \sin 2\theta \\ Y_y &= X'_x \sin^2\theta + Y'_y \cos^2\theta + X'_y \sin 2\theta \\ X_y &= (X'_x - Y'_y) \sin\theta \cos\theta + X'_y \cos 2\theta \end{aligned} \right\} \quad (\text{II})$$

The normal strain $e_{x'x'}$ in the direction of the OX' axis is given by:—

$$e_{x'x'} = e_{xx} \cos^2\theta + e_{yy} \sin^2\theta + e_{xy} \sin 2\theta \quad (\text{III})$$

Substituting the values of the strains as given by equation (I.) in equation (III.), inserting the values of X_x , Y_y and X_y as given by equation (II.), and considering the coefficient of X'_x the following is obtained:—

$$\frac{1}{E_{x'}} = \frac{\cos^4\theta}{E_x} + \frac{\sin^4\theta}{E_y} + \left\{ \frac{1}{\mu_{xy}} - \frac{2\sigma_{xy}}{E_x} \right\} \sin^2\theta \cos^2\theta.$$

Since the x -axis is in the longitudinal direction and the y -axis in the tangential, this can then be written:—

$$\frac{1}{E_\theta} = \frac{\cos^4\theta}{E_l} + \frac{\sin^4\theta}{E_t} + \left\{ \frac{1}{\mu_{lt}} - \frac{2\sigma_{lt}}{E_l} \right\} \sin^2\theta \cos^2\theta$$

where E_l and E_t are the elastic moduli of the veneer parallel to and perpendicular to the grain and E_θ is the elastic modulus at an angle of θ to the grain of the veneer. σ_{lt} is the Poisson's ratio for strain in the tangential direction when stress is applied in the longitudinal direction, and μ_{lt} is the modulus of rigidity for shear in the plane of the veneer.

Experimental values are not available for Poisson's ratios but as $\frac{2\sigma_{lt}}{E_l}$ comprises only a small percentage of the term containing it, the value of σ_{lt} for spruce, namely 0.54, can be used with little error. The theoretical curve of Fig. 3 has been fitted to the experimental data and the value for μ_{lt} for best fit determined. The most probable value appears to be 65,600 lb./sq. in. and using this value the experimental curve does not differ significantly from the fitted curve.

It was found that the means for large angles had a much greater error than those for small angles, despite the fact that more tests had been carried out for larger angles. In fitting the curve a transformation was therefore used. As the variances varied approximately as the square of the mean, the logarithms of the original values, rather than the values themselves, were analysed. The variance of the transformed values was found to be approximately constant. In general, the agreement appears to be reasonably close, the difference being quite small over the greater part of the range. Both in the case of maximum tensile strength and modulus of elasticity the ordinary theoretical formulae used, namely the Hankinson in the former case and the formulae for rotation of axes in material with orthotropic elastic properties in the latter case, give satisfactory

estimates of the values at various angles to the grain, provided the values parallel and perpendicular to the grain and the modulus of rigidity are known.

6. Acknowledgments

The author wishes to thank Mr. E. J. Williams who fitted curves to the experimental points and checked the statistical significance of the departure of the experimental points from the theoretical curves.

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Tests on Small Clear Specimens of North Queensland Kauri (*Agathis palmerstoni* F.v.M.)

By N. H. Kloot, B.Sc.*

Summary.

Mechanical tests have been carried out on five trees of North Queensland kauri. Analysis of the results in great detail was considered unwarranted in view of the small number of trees tested. However, the tests provide sufficient information for comparative purposes and in a comparison with two other species of similar density, viz., bunya pine (*Araucaria bidwilli* Hook.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr), kauri has a lower strength/weight ratio for most of the important properties.

Although a mild form of compression wood was found in all five trees there did not appear any evidence that this affected the results.

1. Introduction

North Queensland kauri is the standard trade common name of the timber known botanically as *Agathis palmerstoni* F. v. M. and is the most important of the three kauris which grow in Queensland, the other two being *Agathis robusta* (C. Moore) F. M. Bail. and *Agathis microstachys* J. F. Bail. and C. T. White. As its name implies, it is a native of Northern Queensland where it is found chiefly on the slopes and in the highlands of the Atherton tableland. The tree is large, averaging 12 to 14 feet girth, breast high, and a total height of over 100 feet (6). An outstanding characteristic is the more or less cylindrical shape of the trunk, the taper being much less than in most species.

The timber ranges in colour from cream to pale reddish-brown. It is usually evenly grown and does not show definite growth rings and although softer and lighter is generally similar to the well-known New Zealand kauri (*Agathis australis* Salisb.).

An annual output of approximately 9 million super feet is absorbed in such fields as cabinet making, joinery, and internal sheeting and flooring of homes and railway carriages. The timber is also used for butter boxes, churns, and pats, for planking of light boats, for marine buoys and floats, and it has a high reputation in templet and pattern making.

At the request of the Queensland Forest Service a short series of tests was made on material from five trees of this species. As far as the author is aware, previous strength tests on kauri pine are scanty and of little practical value.

2. Material

Of the five trees collected for test, two came from the Kuranda district, two from the Little Mulgrave River district, and one from the Kairi district—all of which are within a radius of 50 miles from Cairns. One sawn flitch was selected from each tree, four being cut from middle logs and the fifth from a butt log. Details of the test logs are given in Table 1.

* An officer of the Division of Forest Products.

TABLE 1.—DETAILS OF LOGS TESTED.

Tree No.	Locality.	Annual Rain-fall.	Approx. Elevation.	Slope.	Aspect (mag. bear.).	Soil, Subsoil, and Outcrops.	Type of Forest.	General Appearance of Tree.	Height to First Limb.	Height Overall.	Girth Breast Height.	Logs Selected for Test.
1	T.R. 315, adjoining Bor. 18. Parish of Smithfield. Situated about 40 chains from a large forest pocket. Kuranda district	in. 90	ft. 1,350	1' in 15'	45° E.	Loose grey soil with clayey subsoil	Thick lawyer cane scrub	General taper, clean bole, and broken top. Had only one large limb when felled, the remaining top having been blown off in a cyclone or storm	ft. 64	ft. 84	11' 8"	Butt log, 12' long, stump 1' above ground
2	Part of T.R. 315, Bor. 281. Parish of Smithfield. Situated about 20 chains from a large forest pocket. Kuranda district	90	1,300	Approx. 1' in 1'	335° W.	Loose grey soil—clayey subsoil	Thick lawyer cane scrub	Standing almost perpendicular, good even taper, good top. Portion between first and second limbs, very knotty. Was on a very steep slope immediately above a gorge about 50' deep	64	96	11' 7"	Middle log, 12' long, stump 1' 3" at back and 6' at front above ground

TABLE 1.—DETAILS OF LOGS TESTED.—continued.

Tree No.	Locality.	Annual Rain-fall.	Approx. Elevation.	Slope.	Aspect (mag. bear.).	Soil, Subsoil, and Outcrops.	Type of Forest.	General Appearance of Tree.	Height to First Limb.	Height Overall.	Girth Breast Height.	Logs Selected for Test.
3	Blackwell Creek. R. 675. Parish of Grafton. Little Mulgrave River (Coastal) district	in. 100	ft. 500	5°	360°	Grey stony soil	Poor type rain forest	Fine straight barrelled tree. Was growing near a small gully, in a slightly sheltered position	ft. 55	ft. 95	12' 7"	Middle log, 12' long, 15' above ground
4	Blackwell Creek. R. 675. Parish of Grafton. Little Mulgrave River (Coastal) district	100	500	10°	45°	Grey gravelly soil	Poor type rain forest	Fine straight barrelled tree which was dominating the surrounding forest	61	100	14'	Middle log, 12' long, 21' 6" above ground
5	R. 185. Danbulla Kairi (Tableland Area) district	75	2,500	..	..	Red soil ..	Dense lawyer vine	Good top—healthy tree. Was standing in a valley	..	98	15' 2"	Middle log, 15' long

The sawn flitches, approximately 12 in. by 6 in., were resawn to yield 4 pairs of 2½ in. by 2½ in. tangentially-matched sticks, one stick in each pair being put aside for air-drying, the other for testing green. Specimens from both the dry and green sticks, after having been machined to 2 in. by 2 in., were subjected to the various tests according to the procedure, largely based on A.S.T.M. (1), B.S.I. (2), and British Air Ministry (3) specifications, adopted in this laboratory for the war-time testing of timbers for use in aircraft construction.

3. Correction for Moisture Content

Using an intersection point of 28 per cent. moisture content, the average relationship between strength and moisture content was calculated for each property using the U.S. Forest Products Laboratory exponential formula (7), and the estimated values at 12 per cent. moisture content obtained.*

All properties were corrected by this method with the exception of the two impact tests, toughness and Izod, for which the relationship between strength and moisture content is known to be considerably different from the exponential law for static properties. As yet, however, no tests have been done to determine correction factors for impact tests on this species.

4. Compression Wood

In common with other softwoods, kauri tends to develop compression wood and, in order to determine its severity in the trees tested, microscopic examination was made of specimens from every stick taken from each tree. A mild form of compression wood was found to be present in all the samples examined. It was not, however, sufficiently pronounced to be taken as definite compression wood. Where the latter did occur, it was found only in very narrow bands. These appeared more frequently in the two trees from the Little Mulgrave River district. Less was found in the trees from the Kuranda district, and the tree from the tableland area showed no evidence of definite compression wood.

5. Results of Tests

In Table 2 the average value for each property is given for the green and dry tests together with the appropriate statistical data. No figures are given for dry torsion as only one specimen was available for test, and in the green tests statistical data are not given for the same properties as only three specimens were tested.

In order to check the effect on the results of the compression wood in Tree 3 (the worst of the five trees in this respect) the strength values of the five trees were compared with one another; whilst the differences between trees were found to be significant, the effect was general and could not be attributed to one tree only. Consequently the results from all trees have been included in the species average and no result has been eliminated from any part of the analysis because of the presence of compression wood.

* It will be noted that in Table 4 the results are quoted at 15 per cent. moisture content. This is due to the initial analysis of the results being made uniform with the procedure adopted for other species tested in the aircraft timber testing programme.

TABLE 2.—MECHANICAL AND PHYSICAL PROPERTIES OF SMALL CLEAR SPECIMENS OF NORTH QUEENSLAND KAURI.

Property.	Unit.	Moisture Condition.	Species Mean.	Standard Error of Species Mean.	Standard Deviation of Tree Means.	Characteristics of Frequency Distribution.				Approximate Corrections for 1% m.c. for m.c.'s between 10% and 16%.
						Standard Deviation of Individual Results.	Co-efficient of Variation, per cent.	Observed Minimum.	Observed Maximum.	Number of Specimens.
Moisture content when green	%	..	47.7	..	..	..	..	..	..	..
Density ..	lb./cub. ft.	Green 12%	37.1 29.0	1.24 0.96	2.76 2.14	2.95 2.23	8.0 7.7	32.2 25.3	42.5 32.3	20 19
Basic density (ratio of weight oven-dry to volume green)	lb./cub. ft.	..	25.1	0.84	1.87	2.00	7.7	21.8	28.8	20
Shrinkage— Green to 12% moisture content— Radial ..	%	..	2.2	..	..	..	..	..	..	..
Tangential ..	%	..	3.4	..	..	..	..	..	..	..
Green to oven-dry— Radial ..	%	..	4.0	..	..	..	..	..	..	..
Tangential ..	%	..	5.6	..	..	..	..	..	..	..
Tension parallel to grain— 0.1% Proof stress ..	lb./sq. in.	Green 12%	8,080 14,400	726 1,140	1,620 2,560	2,260 3,710	28.5 26.0	4,770 9,190	11,400 24,900	19 17
Maximum tensile strength	lb./sq. in.	Green 12%	11,000 14,400	577 1,140	1,290 2,560	2,030 3,710	18.5 26.0	6,910 9,190	15,300 24,900	19 17
Modulus of elasticity ..	10 ⁶ lb./sq. in.	Green 12%	0.99 1.21	0.03 0.13	0.06 0.29	0.20 0.29	20.0 24.5	0.58 0.84	1.42 1.91	19 17
										0.01

TABLE 2.—MECHANICAL AND PHYSICAL PROPERTIES OF SMALL CLEAR SPECIMENS OF NORTH QUEENSLAND KAURI.—*continued.*

Property.	Unit.	Moisture Condition.	Species Mean.	Standard Error of Species Mean.	Standard Deviation of Tree Means.	Characteristics of Frequency Distribution.					Approximate Corrections for 1% m.c. between 10% and 16%.
						Standard Deviation of Individual Results.	Co-efficient of Variation, per cent.	Observed Minimum.	Observed Maximum.	Number of Specimens.	
Compression parallel to grain ($2'' \times 1'' \times 1''$ specimen)— Maximum crushing strength ..	lb./sq. in.	Green 12%	3,500 5,970	190 216	424 482	469 519	13.4 8.7	2,520 5,120	4,290 7,230	20 18	.. 176
Compression parallel to grain ($8'' \times 2'' \times 2''$ specimen)— Stress at L.P. ..	lb./sq. in.	Green 12%	2,810 3,430	116 183	259 409	357 549	12.7 16.2	1,880 2,610	3,520 4,590	20 19	.. 39
Maximum crushing strength ..	lb./sq. in.	Green 12%	3,510 5,580	147 210	329 470	456 510	13.0 9.2	2,960 4,380	4,220 6,520	20 19	.. 145
Modulus of elasticity ..	10^6 lb./sq. in.	Green 12%	1.10 1.26	0.04 0.09	0.09 0.20	0.12 0.21	11.0 16.8	0.94 0.90	1.44 1.75	20 19	.. 0.01
Compression perpendicular to grain ($6'' \times 2'' \times 2''$ specimen)— Radial— Stress at L.P. ..	lb./sq. in.	Green 12%	481 709	31.6 36.2	70.6 80.9	93.2 86.1	19.4 12.2	327 586	650 838	12 10	.. 16
0.1% Proof stress ..	lb./sq. in.	Green 12%	556 933	39.4 37.1	88.1 82.9	88.0 86.8	15.8 9.3	475 796	702 1,080	12 10	.. 28

TABLE 2.—MECHANICAL AND PHYSICAL PROPERTIES OF SMALL CLEAR SPECIMENS OF NORTH QUEENSLAND KAURI.—continued.

Property.	Unit.	Moisture Condition.	Species Mean.	Standard Error of Species Mean.	Standard Deviation of Tree Means.	Characteristics of Frequency Distribution.				Approximate Corrections for 1% m.c.'s between 10% and 16%.
						Standard Deviation of Individual Results.	Co-efficient of Variation, per cent.	Observed Minimum.	Observed Maximum.	Number of Specimens.
Compression perpendicular to grain (6" x 2" x 2" specimen)—continued. Tangential— Stress at L.P. 	lb./sq. in.	Green 12%	532	56.8	127	138	24.8	327	704	12
			949	36.2	80.9	177	18.7	663	1,160	10
	lb./sq. in.	Green 12%	597	52.1	116	133	21.2	402	755	12
			1,230	47.4	106	137	11.2	961	1,380	10
Compression perpendicular to grain (2" x 2" x 2" specimen)— Radial— Stress at L.P. 	lb./sq. in.	Green 12%	284	33.7	75.3	85.4	30.0	175	512	16
			..	..	..	..	..	..	..	..
	lb./sq. in.	Green 12%	342	38.2	85.5	88.4	25.7	219	532	16
			..	..	..	..	..	..	..	..
Tangential— Stress at L.P. 	lb./sq. in.	Green 12%	298	22.5	50.2	68.1	22.7	151	402	16
			..	..	..	..	..	..	..	..
	lb./sq. in.	Green 12%	372	30.1	67.2	76.6	20.4	202	503	16
			..	..	..	..	..	..	..	..

TABLE 2.—MECHANICAL AND PHYSICAL PROPERTIES OF SMALL CLEAR SPECIMENS OF NORTH QUEENSLAND KAURI.—continued.

Property.	Unit.	Moisture Condition.	Species Mean.	Standard Error of Species Mean.	Standard Deviation of Tree Means.	Characteristics of Frequency Distribution.				Approximate Corrections for 1% m.c. for m.c.'s between 10% and 16%.
						Standard Deviation of Individual Results.	Co-efficient of Variation, per cent.	Observed Minimum.	Observed Maximum.	Number of Specimens.
Shear— Maximum strength— Plane of failure—Radial ..	lb./sq. in.	Green 12%	769 1,130	49.9 47.0	112 105	115	14.8	570	1,040	15
						130	11.5	901	1,350	10
Plane of failure—Tangential	lb./sq. in.	Green 12%	853 1,110	48.0 46.1	107 103	108	12.5	670	1,020	15
						111	10.0	885	1,240	10
Cleavage— Maximum strength— Plane of failure—Radial ..	lb./in.	Green 12%	156 163	6.69 11.4	15.0 25.4	23.9	15.3	115	205	12
						25.8	15.8	114	204	10
Plane of failure—Tangential	lb./in.	Green 12%	178 374	5.16 11.1	11.5 24.9	31.9	17.7	143	251	11
						34.0	9.1	327	449	10
Izod— Blow applied to radial face ..	ft. lb.	Green *	3.9 1.8	1.14 0.08	2.56 0.19	2.49	63.7	1.3	9.4	20
						0.35	19.4	1.2	2.5	19
Blow applied to tangential face	ft. lb.	Green *	4.2 1.7	1.18 0.18	2.65 0.41	2.71	64.7	1.2	11.5	20
						0.43	25.3	1.1	2.9	19
Toughness— Blow applied to radial face ..	in. lb.	Green *	99.3 50.4	13.7 3.40	30.7 7.61	33.7	34.0	50.2	160	20
						12.8	25.4	19.4	71.0	19
Blow applied to tangential face	in. lb.	Green *	105 50.9	10.7 5.50	23.9 12.3	35.6	33.8	67.4	172	20
						14.6	28.7	26.0	72.3	19
Hardness— Tangential	lb.	Green 12%	526 516	35.4 34.8	79.2 77.1	85.8	16.4	370	675	20
						84.6	16.4	360	625	19

* Average moisture content approximately 16%.

In Plate 2, Figs. 1, 2, and 3 illustrate typical failures of dry kauri pine in centre-point bending, four-point bending, compression parallel to the grain, Izod, and toughness. The pronounced brittle failures in both static and impact bending tests are reflected in the very low impact values.

As the number of specimens tested to determine any particular property was small, it was considered that the preparation of frequency polygons would not serve any useful purpose and might prove misleading.

6. Correlations Between Properties

In attempting to select material with certain minimum strength requirements, it is of advantage to fix on an easily determined property such as density and knowing the correlation between this and the desired properties, to select the timber within a given range or above a given minimum value of this property. This is usually fairly difficult with timber owing to the low correlation obtained between most pairs of properties.

In Table 3 a list is given of those correlation coefficients which proved to be statistically significant. Both dry and green results were analysed together and, where the difference between moisture contents was shown to be not significant, the total correlation and a single regression for both sets of results are given. Where the difference in correlation coefficients for dry and green tests proved to be significant, regressions for both conditions are given and the correlation coefficient with moisture condition eliminated is also shown in place of a total correlation coefficient. Most of the numerically large coefficients are of little practical importance, e.g. radial Izod v. tangential Izod, whereas those which might be of some practical importance are generally too low to be of much assistance in selection. An example of the latter is the correlation between density and maximum crushing strength, which is shown as 0.748. This means that only $0.748^2 \times 100$ or 56 per cent. of the variation in crushing strength is attributable to variation in density.

In Figs. 1 to 6, the results from some of the tests are plotted against density and, with the exception of tensile strength against density where the correlation was not significant, regression curves have been included. It must be emphasized that the total number of test values is relatively small and this analysis can only serve as a guide until a much wider range of material has been tested to obtain a more accurate estimate of the properties and the relationships between properties of this species.

7. Comparison with Other Species

In Table 4 a comparison is made between kauri pine and two other species of similar density, viz. bunya pine and Sitka spruce, the data for which were obtained from an unpublished report on the properties of bunya pine. On the whole, kauri pine does not compare favourably with either of the other two species, particularly in tensile strength, modulus of elasticity, and impact strength. Except in compression

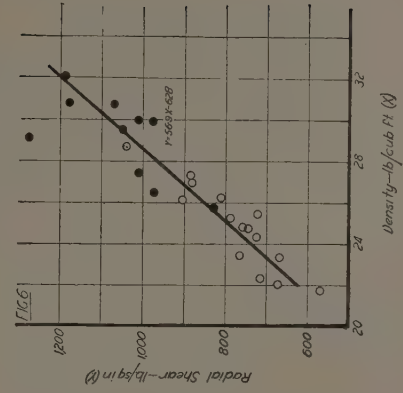
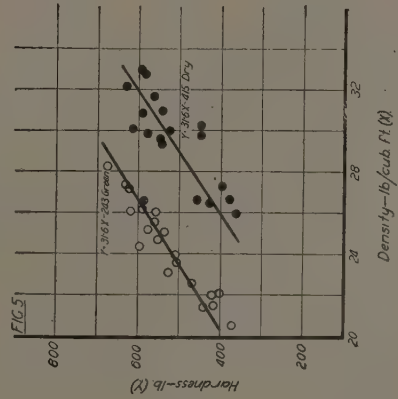
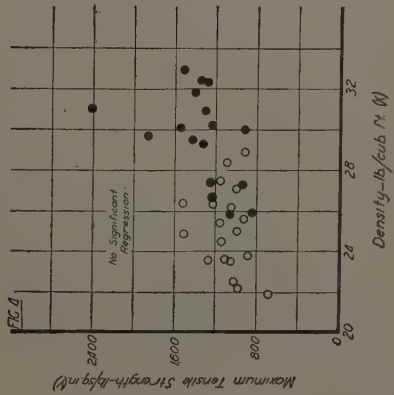
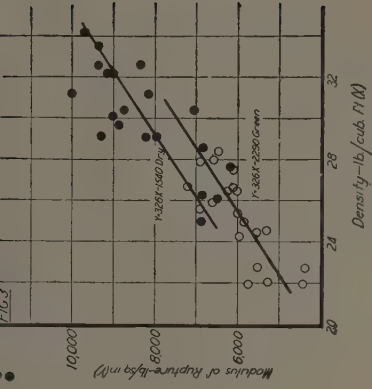
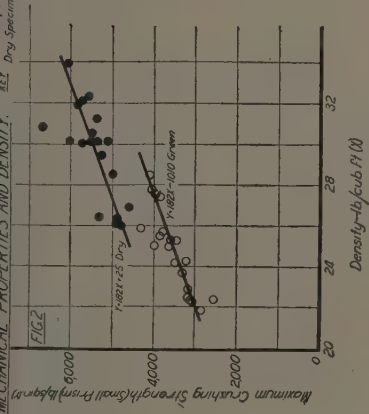
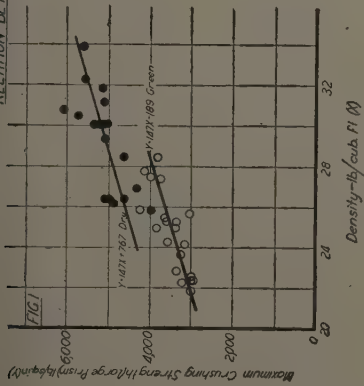


TABLE 3.—NORTH QUEENSLAND KAURI—REGRESSIONS AND CORRELATIONS.

Independent Variable (x).		Dependent Variable (y).		Significance of Difference between Moisture Conditions.	Linear Regression of y on x.	Correlation Coefficients.		
Property.	Unit.	Property.	Unit.			Total.	Within Trees.	Total (Moisture Condition Eliminated)
Maximum crushing strength (small prism)	lb./sq. in.	Hardness	lb.	**	Y (green) = .0138x + 478 Y (dry) = .0138x + 435	..	.502**	.804**
		Maximum crushing strength (large prism)	lb./sq. in.	**	Y (green) = .691x + 1,040 Y (dry) = .691x + 1,420	..	.479**	.980**
		Radial toughness	in. lb.	**	Y (green) = .0246x + 13.4 Y (dry) = .0246x + 81.9	..	.422*	.512**
		Modulus of rupture	lb./sq. in.	†	Y = 1.24x + 1,610	.875**	.574**	..
Density	lb./cub. ft.	Modulus of elasticity (static bending)	10 ³ lb./sq. in.	†	Y = .0813x + 782	.408*	.384*	..
		Maximum crushing strength (small prism)	lb./sq. in.	**	Y (green) = 182x - 1,010 Y (dry) = 182x + 24.8	..	.613**	.249†
		Hardness	lb.	**	Y (green) = 31.6x - 243 Y (dry) = 31.6x - 415	..	.662**	.964**
		Maximum crushing strength (large prism)	lb./sq. in.	**	Y (green) = 147x - 189 Y (dry) = 147x + 767	..	.312†	.748**
		Radial toughness	in. lb.	**	Y (green) = 5.35x - 31.1 Y (dry) = 5.35x - 109.8	..	.596**	.506**

** Significant at the 1 per cent. level of probability.

* Significant at the 5 per cent. level of probability.

† Not significant.

TABLE 3.—NORTH QUEENSLAND KAURI—REGRESSIONS AND CORRELATIONS.—*continued.*

Independent Variable (x).		Dependent Variable (y).		Significance of Difference between Moisture Conditions.	Linear Regression of y on x.		Correlation Coefficients.		
Property.	Unit.	Property.	Unit.				Total.	Within Trees.	Total (Moisture Condition Eliminated)
Density	.. lb./cub. ft.	Radial shear	lb./sq. in.	†	Y = 56.9x — 628		.914**	.687**	..
		Modulus of rupture	lb./sq. in.	**	Y (green) = 326x — 2,290 Y (dry) = 326x — 1,540		..	.415*	.076†
Radial Izod	.. ft. lb.	Tangential Izod	ft. lb.	†	Y = 1.08x — .132		.965**	.746**	..
		Radial toughness	in. lb.	**	Y (green) = 10.2x + 59.6 Y (dry) = 10.2x + 32.5		..	.245†	.690**
Radial toughness	.. in. lb.	Tangential toughness	in. lb.	†	Y = 1.00x + 2.87		.903**	.744**	..
		Maximum tensile strength	lb./sq. in.	*	Y (green) = 48.3x + 6,210 Y (dry) = 48.3x + 11,100		..	.402*	.407*
		Modulus of rupture	lb./sq. in.	**	Y (green) = 13.2x + 4,640 Y (dry) = 13.2x + 7,560		..	.240†	.387*
Maximum tensile strength	lb./sq. in.	Modulus of rupture	lb./sq. in.	**	Y (green) = .175x + 4,010 Y (dry) = .175x + 5,760		..	.424*	.513**

** Significant at the 1 per cent. level of probability.

* Significant at the 5 per cent. level of probability.

† Not significant.

TABLE 4.—COMPARISON OF AVERAGE PROPERTIES OF SMALL CLEAR SPECIMENS (UNSELECTED) OF NORTH QUEENSLAND KAURI, BUNYA PINE, AND SITKA SPRUCE AT 15 PER CENT. MOISTURE CONTENT.

Property.	Unit.	Species Average.			Average/G.*			Average/G ² .		
		Kauri.	Bunya Pine.	Sitka Spruce.	Kauri.	Bunya Pine.	Sitka Spruce.	Kauri.	Bunya Pine.	Sitka Spruce.
Density	lb./cub. ft.	29.5	29.1	28	..	..	..	..	..	..
Air-dry specific gravity at 15% M.C. (G)	..	0.472	0.466	0.448	..	..	..	..	..	..
Shrinkage to 12% M.C.—										
Radial ..	per cent.	2.2	2.0	2.5	..	..	..	..	..	..
Tangential ..	per cent.	3.4	4.0	4.0	..	..	..	..	..	..
Tension parallel to grain—										
Ultimate strength..	lb./sq. in.	13,700	16,700	18,000	29,100	35,800	40,900	..	..	..
Compression. parallel to grain—										
Ultimate strength (2" x 1" x 1" specimen)	lb./sq. in.	5,420	6,200	4,900	11,500	13,300	11,100	..	..	..
Modulus of elasticity	10 ⁶ lb./sq. in.	1.23	1.84	1.80 (est.)	2.61	3.94	4.10	..	..	..
Compression perpendicular to grain (6" x 2" x 2" specimen); load applied to radial face—										
Stress at L.P. ..	lb./sq. in.	660	600	600	1,400	1,300	1,360	..	..	..
Static bending (4 pt. loading)—										
Modulus of rupture	lb./sq. in.	8,220	9,400	8,300 (est.)	17,800	20,200	19,000	24,000	29,500	28,000

* G = Air-dry specific gravity at 15 per cent. moisture content.

TABLE 4.—COMPARISON OF AVERAGE PROPERTIES OF SMALL CLEAR SPECIMENS (UNSELECTED) OF NORTH QUEENSLAND KAURI, BUNYA PINE, AND SITKA SPRUCE AT 15 PER CENT. MOISTURE CONTENT—*continued*.

Property.	Unit.	Species Average.			Average/G.*			Average/G ³ /in.			Average/G ³ .		
		Kauri.	Bunya Pine.	Sitka Spruce.	Kauri.	Bunya Pine.	Sitka Spruce.	Kauri.	Bunya Pine.	Sitka Spruce.	Kauri.	Bunya Pine.	Sitka Spruce.
Torsion—													
Ultimate strength	lb./sq. in.	..	1,790	1,360	..	3,830	3,090	..	5,600	4,630	..	..	..
torsional shear	10 ³ lb./sq. in.	..	98.5	100	..	210	230	..	..	..	..	450	520
Modulus of rigidity		..			..			..			..		
Shear parallel to grain—													
Ultimate strength (average	lb./sq. in.	1,060	1,200	1,020	2,250	2,600	2,320	..	..	..	..	..	..
radial and tangential) ..													
Cleavage—													
Ultimate strength (average	lb./in.	245	190	210	520	410	480	..	..	..	..	..	..
radial and tangential) ..													
Izod—													
Blow applied to radial face	ft. lb.	1.8	4.0	5.5	3.8	8.6	12.5	..	..	..	..	..	..
Toughness—													
Blow applied to radial face	in. lb.	50	64	83	107	140	190	..	..	..	..	..	..
Hardness—													
Tangential face ..	lb.	520	500	480	1,100	1,070	1,090	..	..	..	..	..	..

* G = Air-dry specific gravity at 15 per cent. moisture content.

parallel and perpendicular to the grain and one or two minor properties, kauri is inferior to both bunya pine and spruce and in either of these two species a more efficient solid Euler strut (strength/density²) or a more efficient solid spar (strength/density^{3/2}) may be constructed.

8. Properties Other Than Strength

Experiments on the steam bending qualities of this species (5) show it to be inferior to such species as celery-top pine (*Phyllocladus rhomboidalis* L.C. Rich.), radiata pine (*Pinus radiata* D. Don) and Corsican pine (*Pinus laricio* Poir.). Like hoop pine, kauri has little resistance to decay.

In general, kauri has many desirable qualities as evidenced by the wide range of uses to which this species is put. It is characteristically clear and straight-grained and little difficulty is encountered in its seasoning. It machines and glues well and its almost complete lack of odour and "taint" makes it an ideal medium for food containers such as butter boxes. Data given by Greenhill (4) indicate that kauri has a low shrinkage of the order of 0.2 per cent. per 1 per cent. moisture content change in both the radial and tangential directions.

9. References

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The Nature of Plastic Deformation in Wood at Elevated Temperatures

By H. G. Higgins, B.Sc. (Hons.),* and Florence V. Griffin.*

Summary.

1. Elastic after-effects were observed in hoop pine plywood panels which had been oven-dried and subjected for five minutes to pressures capable of causing residual deformation at elevated temperatures.

2. For the major residual deformations observed, elastic after-effect comprised about half of the total residual deformation at a pressing temperature of 120°C., a proportion which declined to one-seventh at 200°C.

3. The influence of elastic after-effect was such as not to alter radically the effect of temperature upon yield-value.

4. Microscopic studies showed that the radial pressure required to produce fracture of the cell wall declined with increase in temperature, the effect being linear over the range examined, with a regression coefficient of -6.75 lb./sq. in. per degree C.

5. From a consideration of temperature and pressure effects, three main zones of deformation could be defined: those of elasticity, flow, and fracture. The zone of flow was divisible further into areas of plasto-elasticity and visco-elasticity.

6. It appeared probable that the location of flow in the wood tissue was the cell wall as well as the middle lamella zone.

7. Deformation in the zone of flow appeared to involve re-arrangement on a sub-microscopic scale, insofar as gross fracture of the cell wall was absent, and minute compression failures were not significantly more abundant than in the zone of elasticity.

8. Rheological studies may contribute to the knowledge of the structure of the cell wall. Short loading times and elevated temperatures should be used in conjunction with sustained loading at ordinary temperatures.

1. Introduction

In a previous paper (1) an experiment, which was designed to investigate the effect of temperature upon the immediate residual deformation of plywood panels pressed for a fixed time under varying loads, was described. It was found that, for oven-dry material, the load at which appreciable residual deformation took place declined rapidly with rising temperature from 120° to 160°C., and was small over 160°C. The virtual disappearance of a yield value near this temperature appeared to represent a fundamental change in plastic behaviour.

Two major problems were suggested by the results of this investigation: firstly, what part of the immediate residual deformation can be attributed to elastic rather than plastic effects? and secondly, what is the physical nature of so-called plastic deformation in a material of such complexity as wood?

The answer to the first question would involve the measurement of elastic recovery in the original specimens after the lapse of a considerable period. This would permit due allowance to be made

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for the elastic after-effect in defining the dependence of yield value upon temperature, and the results could be compared with those obtained by measuring residual deformation immediately after pressing.

The second problem sought confirmation or otherwise of the implied hypothesis (1) that each residual deformation was due, in part at least, to plastic behaviour of the material of the wood, and was not simply the result of crushing, i.e., fracture, of the cells. Some evidence was provided in support of this view in that temperature critically controls the mode of deformation, an apparently plastic or quasi-plastic behaviour being superseded by viscous or quasi-viscous flow above about 160°C., and it was remarked that this temperature accorded with the softening point of some dry extracted lignins. It was the aim of the present investigation to obtain further evidence directly of the nature of plastic deformation by microscopic examination of sections of the specimens.

2. Materials

The material used for this experiment was identical with that used previously (1), and consisted of plywood specimens 4 in. by 4 in., made up from three veneers, of nominal thickness 1/16 in., of rotary-cut hoop pine (*Araucaria cunninghamii* Ait.), bonded together at 50 lb./sq. in. and 145°C. for eight minutes with a phenol-formaldehyde film adhesive. All the specimens had been cut from the same plywood panel, and the veneer consisted of closely matched material from the same log. The specimens had been subjected to pressures ranging from 200 to 1,200 lb./sq. in. over a temperature range of from 120° to 200°C. Each specimen had been oven-dried and then pre-heated for two minutes before the application of the load, which had been maintained for five minutes in every case. Residual deformation had been measured by obtaining the differences in thickness immediately before insertion in and immediately after removal from the press.

3. Determination of Elastic After-effect

After the lapse of periods of 55 and 100 days from pressing, the thickness of each specimen was re-measured, using a micrometer gauge as before, each determination being the mean of eight measurements—one in each corner and one near the centre of each side. The specimens were oven-dried before measuring in order to reproduce the original moisture content and to eliminate dimensional changes due to the absorption of moisture since pressing. However, most of the recovery must have taken place at a moisture content in equilibrium with laboratory conditions.

4. Influence of Elastic After-effect on Yield Line

The elastic after-effects are shown in Table 1, and it can be seen that the major part of the delayed recovery occurs in the first period of 55 days after pressing, indicating that the total effect converges to a finite limit, which will be a small multiple of the recovery observed in the first period.

TABLE 1.—RESIDUAL DEFORMATION AND ELASTIC AFTER-EFFECT.

—		Pressure (lb./sq. in.)	Temperature (° C.).														
			120.			140.			160.			180.			200.		
			a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
Total Residual	200	5	8	..	3	2	..	5	5	..	8	10	6	3	8	2	
Deformations	400	2	3	..	5	3	..	11	5	*	22	17	13	18	21	15	
(In. $\times 10^{-3}$)	600	2	0	..	4	2	..	23	15	*	36	27	21	81	70	68	
Compression	800	5	-6	..	11	7	6	19	14	7	56	45	36	235	209	204	
Positive	1,000	2	2	..	33	25	21	60	38	30	232	177	168	505	449	447	
	1,200	43	21	24	89	60	55	260	200	187	414	320	304	639	554	559	
Total Elastic	200	0	-3	..	0	1	..	0	0	..	0	-2	2	0	-5	1	
After-effect	400	0	-1	..	0	2	..	0	6	*	0	5	9	0	-3	3	
(In. $\times 10^{-3}$)	600	0	2	..	0	2	..	0	8	*	0	9	15	0	11	13	
Recovery	800	0	11	..	0	4	5	0	5	12	0	11	20	0	26	31	
Positive	1,000	0	0	..	0	8	12	0	22	30	0	55	64	0	56	58	
	1,200	0	22	19	0	29	34	0	60	73	0	94	110	0	85	80	

a = Immediately after pressing.

b = 55 days after pressing.

c = 100 days after pressing.

* Specimens delaminated.

If the residual deformations after 55 days, for example, are plotted against the pressure, for each temperature, a family of curves is obtained (see Fig. 1), which is similar to that obtained for the

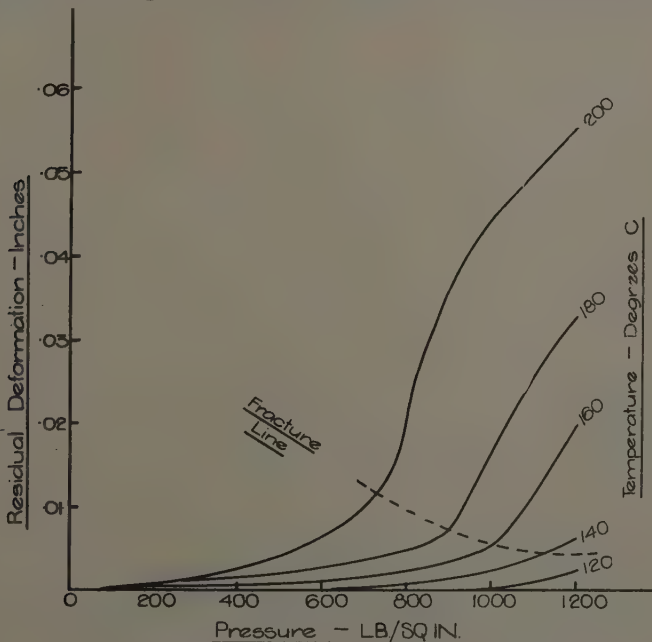


FIG. 1.—Residual deformation 55 days after pressing.

immediate residual deformations (1). From these new curves a new yield value versus temperature curve ("yield line") can be drawn, the yield values being taken, as before, as the pressures corresponding to the points at which the smoothed curves in Fig. 1 approach the load axis (or, in practice, intersect the $+0.0005$ in. abscissa). The new yield line (Fig. 5—lower line) is similar to that obtained using immediate residual deformations.

The dependence of elastic after-effect upon both pressure and temperature is defined, in Fig. 2, by contours on the surface representing the empirical function which expresses that dependence. The

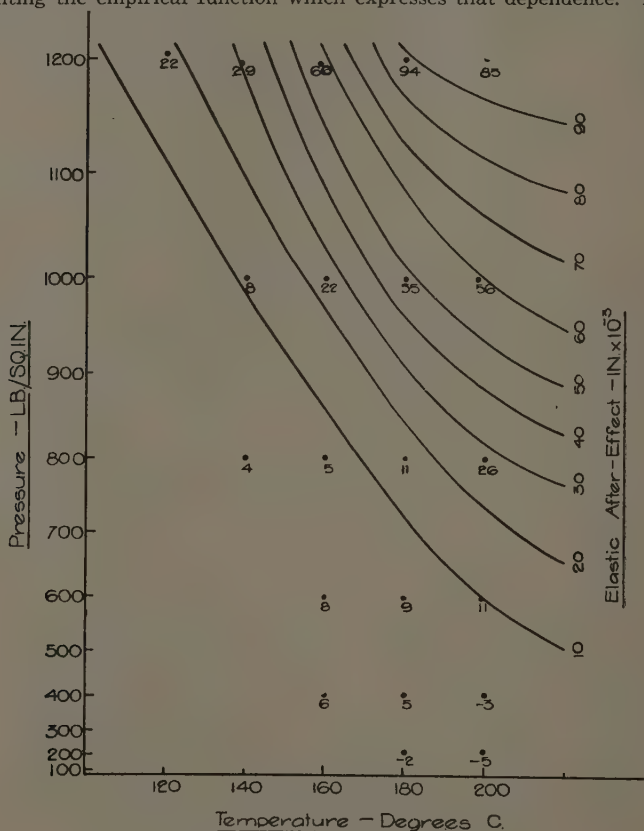


FIG. 2.—Elastic after-effect 55 days from pressing.

contours have been drawn from the elastic after-effects at 55 days, and, to facilitate interpretation, the square of the pressure has been plotted along the vertical axis. Since the temperature and moisture content of the specimens during the recovery period differed from those during pressing, the diagram can be considered as of only practical significance.

5. Effect of Temperature on Elastic After-effect

Although quite valid practically, Fig. 2 gives a somewhat false theoretical conception of the dependence of elastic after-effect upon pressing temperature, since the apparent increase of one with the other at constant pressure is due to the great increase in plasticity with rising temperature. This may be shown by the simple expedient of determining what proportion of the total initial residual deformation is due to elastic after-effect at each temperature. Table 2 shows this proportion expressed as a percentage and, in order to eliminate experimental inconsistencies for small measurements, the ratio has been computed only for elastic after-effects greater than 0.001 in., and at pressures and temperatures greater than the yield value.

TABLE 2.—RATIO OF ELASTIC AFTER-EFFECT TO TOTAL INITIAL RESIDUAL DEFORMATION (PER CENT.).

Pressure (lb./sq. in.).	Temperature (° C.).									
	120.		140.		160.		180.		200.	
	b	c	b	c	b	c	b	c	b	c
600	..	..	..	..	..	..	..	..	14	16
800	..	..	..	..	..	..	30	34	11	13
1,000	..	..	..	..	37	50	24	28	11	11
1,200	51	44	33	38	23	29	23	27	13	12
Time Means	51	44	33	38	30	40	26	30	12	13
Temp. Means	48		36		35		28		13	

b = 55 days after pressing.

c = 100 days after pressing.

The correlation between temperature and the ratio of elastic after-effect to total initial residual deformation is expressed in Fig. 3, which is plotted from the figures in Table 2. It now becomes apparent that elastic after-effect decreases in importance with rising temperature, rather than increasing as suggested by Fig. 2. It is probable that delayed elastic recovery was inhibited to some extent by the cooling of the specimens after pressing.

6. The Relationship between Types of Deformation and Organization of the Cell Wall

The continued existence of elastic after-effects with pressing temperatures above that at which the yield value becomes small, may shed light on the general nature of the deformation above this critical temperature (160°-170°C.). This elasticity immediately excludes, as might, of course, be expected for wood, even at high temperatures, the possibility of Newtonian or true viscous flow, and it indicates further that the behaviour at such temperatures is of the visco-elastic type. The terms used here are in accordance with the classification of strains proposed by the British Rheologists' Club (4) and discussed by Scott Blair (6, p. 43).

Similarly, below the critical temperature, since elastic after-effects cannot occur in any plasto-inelastic system, of which the Bingham solid is a special case, the deformation must therefore be of the plasto-elastic type, as it is in wood at ordinary temperatures.

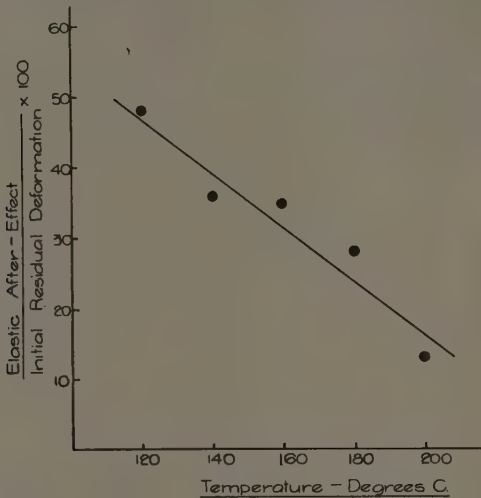


FIG. 3.—Effect of temperature on relative elastic after-effect.

Although by no means conclusive, it seems reasonable to suggest that visco-elastic or plasto-elastic flow would be much more likely to occur in a system consisting of two (or more) discrete materials, perhaps quite intimately linked, but nevertheless maintaining to some degree their individual response to deforming stresses. If definite evidence can be adduced along these lines, it may be possible to draw important conclusions concerning the organization of lignin and of carbohydrates in the plant cell wall. It will be necessary to demonstrate that flow actually takes place in the cell wall, and not merely in the middle lamella zone, a postulate which will be defended later.

Houwink (2, p. 250) points out, moreover, that correlation between the orientation and length of the micelles and the shape of the deformation curves has been established in the case of some cellulosic materials. Van Iterson (9) for instance studied the deformation curves for cellophane in different directions, and found distinct differences which he ascribed to orientation of the micelles. The method could perhaps be applied analytically for natural materials.

7. Microscopic Examination of the Cell Wall

Two sections of each plywood specimen were cut and mounted on slides in Canada balsam. One section of each pair showed a cross-section of the centre veneer and a radial section of the two

face veneers, while the other section, cut at right angles to the first, showed the centre veneer in radial section and the faces in cross-section.

Examination of the sections was made under ordinary light, and in random order so as to eliminate any possible personal bias, with a view to determining in which specimens crushing or fracture had taken place. Radial sections yielded little or no information in this regard, but the cross-sections were clearly divisible into two groups. One showed no evidence of crushing, in the sense of fracture of the cell wall, although in some specimens deformation of the tracheids had apparently taken place in a manner which could have been attributed to a flow phenomenon. The other group showed definite bands in which complete fracture of the cell wall had taken place.

Plate 3 (a) shows a photo-micrograph of a specimen without fracture. Plate 3 (b) and (c), by way of contrast, displays cell wall fracture in different degrees of advancement. Incipient in 3 (b), it is very much advanced in 3 (c), where the orientation of the fracture zones into parallel bands is no longer evident.

It can be seen, by examination of the less fractured specimens, that this orientation is due to fracture occurring parallel to the growth rings, and, as would be expected, it is in the large, thin-walled cells of the early wood that fracture takes place initially. This is shown in Plate 3 (b).

The specimens were examined further in polarized light, with the object of determining the incidence of slip planes and minute compression failures. Slip planes were observed in all sections, and minute compression failures only in those cut from specimens which had been pressed under the following sets of conditions:—

Pressure (lb./sq. in.)	200	400	400	600	800	1,000	1,000	1,200	1,200	1,200
Temperature (°C.)	160	120	180	140	200	140	200	120	140	160

8. Effect of Pressure and Temperature on Cell Wall Fracture

Table 3 lists the temperatures and pressures to which specimens of the two groups were subjected. Except where otherwise indicated, the cell wall fracture occurred in none or all of the veneers of the plywood. The values of the pressure at which fracture occurred (see column headed "Interpolated from Observations") represent the pressure at which fracture would be expected to occur in 1.5 veneers, i.e., in half the total number. When these values of "fracture pressure" were statistically examined in relation to temperature, a linear regression was established with a coefficient of -6.75 lb./sq. in. per degree C., which gave the estimated values shown in the last column of Table 3. The regression was computed by Mr. E. J. Williams of the Section of Mathematical Statistics, C.S.I.R.

These results are shown graphically in Fig. 4 in which the abrupt and approximately linear nature of the boundary between the zones of fracture and of non-fracture on the pressure-temperature diagram

is clearly seen. It is of interest to note that if the fracture pressures for each temperature are plotted on the pressure versus residual deformation curves for any period after pressing (e.g., 55 days, as in Fig. 1) then the points obtained are those at which the slope of the isothermals rapidly increases, thus providing the physical explanation for that phenomenon. These points are joined by the broken line in Fig. 1.

TABLE 3.—VARIATION OF "FRACTURE PRESSURE" WITH TEMPERATURE.

Temp. (° C.).	Pressures Applied to Specimens Showing no Fracture (lb./sq. in.).	Pressures Applied to Specimens Showing Fracture (lb./sq. in.).	Pressure at which Fracture Occurs (lb./sq. in.).	
			Interpolated from Observations.	From Linear Regression.
120	200, 400, 600, 800, 1,000, 1,200 ..		1,200	1,275
140	200, 400, 600, 800, 1,000* ..	1,200† .. .	1,100	1,140
160	200, 400, 600, 800, 1,000* ..	1,200 .. .	1,050	1,005
180	200, 400, 600, 800 ..	1,000, 1,200 ..	900	870
200	200, 400, 600 ..	800, 1,000, 1,200 ..	700	735

* Fracture in one veneer.

† Fracture in two veneers.

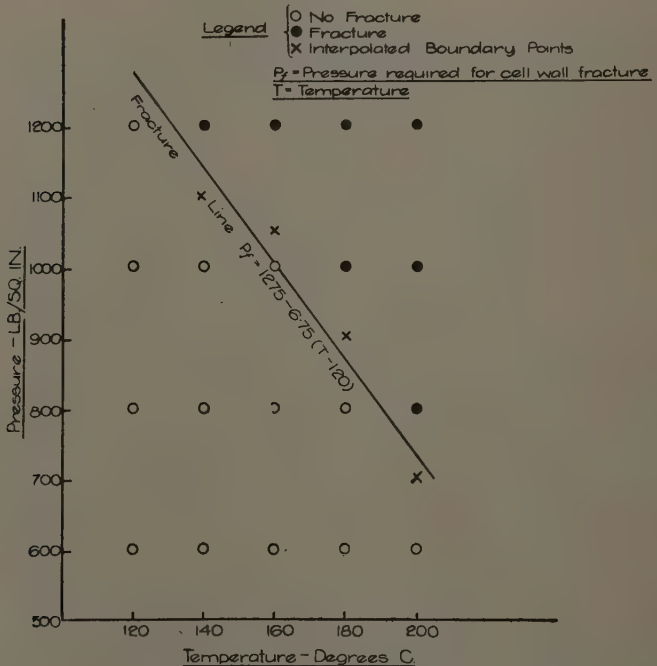


FIG. 4.—Effect of temperature on strength of cell wall.

9. Principal Zones of Deformation

The effect of temperature upon both yield value and "fracture pressure" is shown in Fig. 5, the yield line being arbitrarily selected as that corresponding to conditions 55 days after pressing, and the fracture line being taken directly from Fig. 4.

Three major zones of deformation are now defined. The lower zone is that of elastic deformation; nothing can be said from the present data as to whether further boundaries can be drawn within the zone, e.g., between Hookean and non-Hookean deformation. However, it may be noted that the proportional limit can never exceed the yield value and can only equal it if all the elastic deformation follows Hooke's Law—a rather improbable condition, perhaps, in dry wood at any temperature. The upper zone is that of fracture of the cell wall, and as such is practically beyond rheological study, although, in compression, complex plastic and elastic effects will continue to operate with increasing stress, even as failure proceeds. Our main interest in this zone at present, however, is in its lower boundary, and in particular in the large distance by which that line is removed from the yield line, and even from the position the yield line would be expected to occupy after the final appreciable dissipation of elastic after-effect.

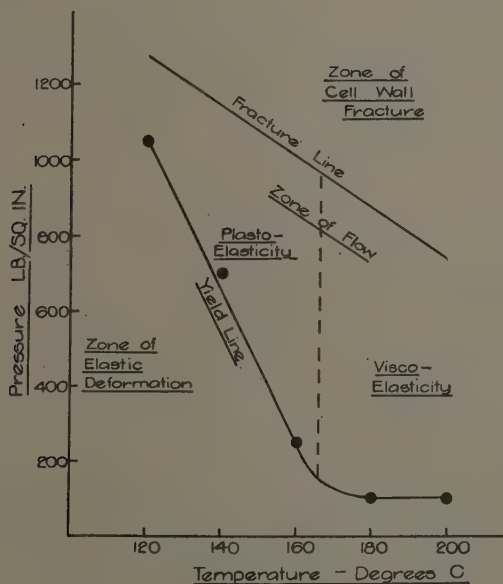


FIG. 5.—Zones of deformation.

It is in the middle zone of Fig. 5, then, between the fracture line and the yield line that plastic deformation is of major importance. A further sub-division of this zone can be made at the critical temperature into plasto-elastic and visco-elastic deformation. It seems fairly

reasonable to assume that this boundary is an isothermal, since the type of flow should not depend on stress, within such narrow limits, once the yield value is exceeded.

The question of the location of flow deformation within the woody tissue is worthy of passing consideration, although the evidence is somewhat limited. From simple geometrical considerations, it would appear that the very fact that permanent external volumetric compression takes place under stress, without fracture of the cell wall, indicates that the deformation cannot be solely in the middle lamella zone. It seems justifiable to conclude that flow must also take place in the material of the cell wall, which comprises the main bulk of the tissue. (Support for this view is perhaps lent by the recent conclusion of Wardrop and Dadswell (10) that intercellular adhesion in *delignified* tissue is to be attributed mainly to direct mechanical adhesion between the cells, and that the previous conception of a dilute alkali soluble, non-lignin, non-polyuronide bonding material must be rejected.)

Reverting to Fig. 5, one practical application of the division of the pressure-temperature diagram into zones of deformation may lie in defining conditions for the manufacture of densified wood products having optimum strength/weight ratios. For a particular species, time of pressing, and moisture content, it would be necessary to select temperature and pressure so as to exceed the yield line in order to obtain permanent densification. On the other hand it seems very probable that strength properties will not continue to increase much more rapidly than density if the fracture line is exceeded. Best results could possibly be obtained at temperatures and pressures just below the fracture line.

10. General Discussion.

Some diffidence has been felt by one of the present writers in a previous paper (1) in using the term "yield value" to connote the compressive stress at which appreciable permanent deformation takes place, a meaning which has been retained in these discussions. Various definitions of the "yield value" of some materials, usually based on the tensile stress required for an arbitrary small permanent extension of a rod of fixed length, have been proposed. There seems to be no general agreement among rheologists as to what is meant by the term (6, p. 184) and indeed the acceptance or otherwise of the concept of "yield value" forms the basis of the difference between the analytical and integralist schools in rheology. So the term "yield value" is used here in its widest sense with full cognizance of the necessarily arbitrary conditions imposed by the present tests: namely, the moisture content of the wood, the time and rate of loading, the species, &c. However, the qualitative picture may be of some use.

The short loading time used need not be considered as incompatible with generally applicable conclusions on the plasticity of wood. Insofar as elevated temperatures have an effect similar to long-time loading in increasing residual deformation, the study of wood at these temperatures can provide data for correlation with the study of creep at ordinary temperatures, and of course these data can be much more quickly obtained. Tests conducted at ordinary temperatures

and with long-time loading are of vital importance for direct application to problems in constructional engineering, as Kingston (3) points out; tests at elevated temperatures with short loading time are more applicable in practice to the manufacture of derived wood products, e.g., plywood and densified wood, and plastics containing wood flour. For clarification of the theory of flow in wood, both lines of attack are necessary.

The decline with temperature of the strength of the dry material of the cell wall, as determined by the pressure required for fracture, suggests that methods, such as those described here, may yield data which will contribute to the intimate problems of cell wall structure, particularly when used in conjunction with the rheological analysis suggested earlier. Such an approach has been adopted by Treitel for cylindrical plant tissues (8).

Results of the microscopic examination of the sections in polarized light indicated that minute compression failures are not significantly more abundant in the middle zone than below the yield line, which suggests that the plastic deformation in the zone of flow involves micellar or molecular re-arrangement rather than any form of crushing, even on a microscopic scale. In this connection it is of interest that another recent paper by Wardrop and Dadswell (11) indicates that, for certain tests carried out at ordinary temperatures under very different conditions from the present ones, short-time loading produced no widespread minute compression failures, whereas there was some development of minute compression failures in beams loaded for long periods. However, the stresses were high. A point in favour of the assumption of a true form of plasticity in the middle zone of Fig. 5 is the well-known plasticizing action of moisture upon wood, which has been discussed quantitatively by Seborg, Millett, and Stamm (7) and briefly by one of the present writers (1).

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The Influence of Fertilizers on Take-All of Wheat

By H. R. Angell, Ph.D. *

Summary.

1. Infection of roots of wheat by root-rotting organisms in differently fertilized plots in a randomized block was not significantly different from the controls.

2. Soil moisture not having been a limiting factor in 1943, the percentage of whiteheads was, in comparison with the controls, significantly lower in the plots manured with a mixture of ammonium sulphate and superphosphate, with or without trace elements.

3. The effects of some other fertilizers are also noted.

4. Variation in the percentages of plants with whiteheads or incipient whiteheads in different manurial treatments suggests that the economic importance of the disease is significantly influenced by available plant food.

5. Using the control plots as the basis of comparison, the percentages of plants with infected roots in the different treatments are not significantly different, but the percentages with whiteheads or incipient whiteheads are significantly different. The difference between the percentage of root infection and the percentage of whiteheads appears to indicate induced resistance to the development of the disease in the plant.

6. The bearing of these results on the control of take-all, and some factors that may interfere with control are discussed.

1. Introduction

It has been stated by Russell (11) that *Ophiobolus graminis* Sacc., the organism associated with take-all of wheat, *Triticum aestivum* L., is present in the virgin sod in Saskatchewan. Since that time it has become apparent that "the widespread occurrence of take-all as a disease of cereal crops is undoubtedly to be attributed to the cosmopolitan distribution of *O. graminis* as a root disease of grasses" (Garrett, 6). From the results of the writer's experiments and observations, it has been evident that this view concerning the distribution of the organism holds true under the conditions prevailing in the Australian Capital Territory.

In experiments in drums the writer (1, 2) showed that in the second season the disease was of little consequence if plant food was conserved from the first season's crop, but was destructive if plant food was depleted by it. In the experiments, the soil in some of the drums was infested with a culture of the organism in the first year, to other drums nothing was added, but naturally occurring root-rotting organisms were present as was shown by the occurrence of lesions at harvest time. In the first year the disease caused marked under-development of the plants in the artificially infested drums, consequently a larger supply of nutrients was conserved in those drums for the second year's crop. In the drums that were not artificially infested the plant food was nearly exhausted by the crop in the first season, little nutrient remained for the needs of the second season's crop, consequently take-all was destructive.

In a recent paper by White (16) and in the literature reviewed by Garrett (6) it is assumed that control of the disease after fallowing is due mainly to the elimination of root-rotting organisms from the

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soil. The relative efficiency of two years of bare fallow and two years of pasture, respectively, in reducing the percentage of take-all should, however, be noted (16). In the present paper there is evidence that the percentage of plants with infected roots in the differently manured plots does not differ significantly from that in the controls, though there are differences between some of the treatments. The differences in the percentages of plants with whiteheads, however, show that susceptibility to the progress of the disease is conditioned by the nutrients added to the soil (1, 2). The degree of damage to the roots also appears to be influenced by plant food (4, 13). The results of these pot and plot experiments suggest that control of take-all by fallowing may be due to available plant food (3, 8) and not to the elimination of root-rotting organisms.

Extension of the writer's experiments from pots to field plots was facilitated by the cooperation of a wheatgrower on a farm eight miles from the laboratory in Canberra. The disease was destructive in 1939 when wheat was first sown on the area used for this experiment. The history of the field, the soil type, and the distribution of the disease in 1939 and 1940 were discussed by White (15). The experiment here described was conducted in 1943 on a plot in this field in which wheat was grown every season since 1939. White (16) reported that on this area in 1942 the percentage of take-all was 76 and 72 per cent.

The effects of added nutrients on the host, on infection, and on disease development under the conditions prevailing in 1943 are here reported and discussed.

2. Field Experiment—Methods

The usual tillage operations were done and the seed was sown in late autumn as is usual in this area.

The experiment was designed as a randomized block arrangement of four replications with eight plots, each 25 feet by 25 feet, per block. In each block, a mixture of the trace elements listed below was applied to one of the plots and a mixture of the same trace elements and superphosphate to another. These plots were then halved and ammonium sulphate applied to one half. Within each block there was also a control plot to which nothing was added. The remaining five plots per block were given the following treatments:—

Superphosphate.

Ammonium sulphate with and without superphosphate.

Blood manure with and without superphosphate.

Wherever used, the rates of dressing were—

Ammonium sulphate	..	..	8 cwt./acre.
Superphosphate	..	..	5 cwt./acre.
Blood manure ..	..	..	8 cwt./acre.
Zinc sulphate	..	..	12.0 lb./acre.
Manganese sulphate	..	..	12.0 lb./acre.
Copper sulphate	..	..	3.6 lb./acre.
Borax ..	..	..	0.6 lb./acre.
Ammonium molybdate	..	..	0.6 lb./acre.

The growing conditions from seeding to maturity were much better than is usual in this district. The rainfall was well distributed, the monthly totals taken at the experiment station nearby being given below.*

Quadrat samples were taken from each plot in December when the ears could be sharply differentiated as healthy, intermediate, or white-headed. The ears of intermediate type were distinguished by their greyish-green hue, and such ears if left to mature would have produced pinched to very pinched grain. For treatment comparisons it was decided to group them with plants with whiteheads.

The root systems were examined for lesions and rated according to whether lesions were present or absent. Under the circumstances it was impracticable to estimate the amount of root damage, either in the absolute or relative sense. Estimates of the amount of damage to roots and the relation to whiteheads or other signs of take-all in other experiments were dealt with elsewhere (1, 2).

The mean number of ears per plant was recorded as an index of shoot development.

3. Results

The results are given in Table 1. For the ratings of health of roots and ears, the variance between replicates of a treatment and the corresponding mean were approximately proportional, making it necessary to use the square root transformation of the ratings before analysis. The means of the transformed values, together with minimum differences for significance at the 5 per cent. and 1 per cent. level are given. Because of the design, the error appropriate to the estimate of ammonium sulphate effects in the presence of the trace elements with or without superphosphate, is different from the error for the remaining comparisons.

The principal feature of the results shown in the table is the one with which this paper is primarily concerned. It is the generally beneficial effect of the application of a mixture of ammonium sulphate and superphosphate, with or without the trace elements. The beneficial effect of these fertilizer treatments is shown in the significant increase in the number of ears per plant, and the relatively small percentage of whiteheads or incipient whiteheads. By contrast, in none of the plots is the percentage of plants with healthy roots significantly different from the controls. There are, however, three treatments: No. 10—trace elements plus superphosphate plus ammonium sulphate, No. 4—superphosphate plus ammonium sulphate, and No. 5—blood manure, in which the percentage of plants with healthy roots is significantly higher than in two other treatments, No. 2—ammonium sulphate only, and No. 7—trace elements only. With the high percentage of plants with healthy roots a high average number of ears per plant is associated.

In one fertilizer treatment—the trace elements and ammonium sulphate—the low percentage of whiteheads is in marked contrast with the high percentage in the corresponding ammonium sulphate

* January 246 points, February 8 points, March 89 points, April 350 points, May 262 points, June 33 points, July 122 points, August 204 points, September 220 points, October 297 points, November 344 points, December 161 points. Total 2,336 points.

TABLE 1.—SUMMARY OF RESULTS OF FIELD EXPERIMENT.

Treatment.	Percentage of Whitehead and Intermediate Types.		Percentage of Plants with Healthy Roots.		Mean Number of Bars per Plant.
	Mean Value	Mean of Square Root Transformed Values.	Mean Value.	Mean of Square Root Transformed Values.	
1. Control	15.60	3.38	15.15	3.85	1.35
2. Ammonium sulphate	13.15	3.12	7.90	2.28	1.64
3. Superphosphate	13.40	3.25	16.72	4.07	1.23
4. Superphosphate plus ammonium sulphate	2.32	0.75	19.25	4.30	2.67
5. Blood manure	12.57	3.13	20.32	4.28	2.10
6. Blood manure plus superphosphate	7.80	2.52	14.15	3.62	1.92
7. Trace elements	46.57	6.73	7.70	2.35	1.16
8. Trace elements plus ammonium sulphate	0.45	0.46	6.85	2.43	1.63
9. Trace elements plus superphosphate	21.30	4.22	10.70	3.05	1.48
10. Trace elements plus superphosphate, and ammonium sulphate	0.40	0.32	33.57	5.42	2.25
Minimum difference for significance at 5 per cent. and 1 per cent. between treatments 7 and 8 or 9 and 10	..	1.73, 2.61	..	1.70, 2.58	0.87, 1.32
Minimum difference at 5 per cent. and 1 per cent. between any other treatment pairs	..	2.41, 4.03	..	1.92, 3.21	0.65, 1.09

only. The high percentage of whiteheads in the plots receiving only the trace elements is outstanding. The reasons for the divergences cannot be deduced from the present results. Pot experiments have yet to be made to test the effects of these specific mixtures of fertilizers on the soil from this field. For the same reason the trend with blood manure and superphosphate cannot now be discussed. The failure to obtain a satisfactory response from the addition of superphosphate alone is not surprising, because in pot experiments now in progress with this soil no advantage over the controls results from the addition of superphosphate alone.

4. Discussion

In the field experiment dealt with in this paper, it is apparent that infection of the roots of wheat by *Ophiobolus graminis* occurs very generally, almost independently of ordinary fertilizer treatments, indicating that some degree of root infection might be usual. The development of the disease as gauged by the percentage of empty or nearly empty heads is very different, being closely associated with treatment of the soil. The difference between the percentage of plants with root infection and the percentage of plants with diseased heads can therefore be used as an indication of host susceptibility modified by the various soil treatments.

Under the conditions prevailing during the season, in which there was an equitable distribution of the rainfall, the supply of soil moisture was adequate for the needs of the crop, and a well marked degree of control was obtained in the plots in the experimental area to which a mixture of an inorganic nitrogenous fertilizer and superphosphate was applied. With a comparable soil moisture supply, it is likely that equally good control of take-all would be obtained on the average wheat farm by the natural accumulation of nitrogen in fallowed land, and the usual application of superphosphate. Call (3) has concluded from his experiments in Kansas that "early ploughing in preparing land for wheat appears to be of value under eastern Kansas conditions rather because of the large supply of plant food liberated, especially nitrates, than for any additional moisture that is stored in the soil by the early cultivation. It also appears that poor results are secured from late ploughing chiefly because plant food is not liberated in sufficient quantities to supply the needs of the crop." Richardson and Gurney (8) have shown that under the conditions prevailing at the Waite Agricultural Research Institute, South Australia, the amount of nitrate nitrogen accumulated in the soil by fallowing was sufficient for a prolific wheat crop, a basal dressing of 288 lb. of superphosphate per acre being added at sowing time. They also have stated that soil moisture conservation in the fallowed land was only slightly higher than in stubble land. They also have found that the application of $\frac{1}{2}$ cwt. to 2 cwt. of sulphate of ammonia to stubble land gave profitable increases in the yield of crops sown on stubble. Clark (4) has demonstrated that the degree of control of the root-rotting phase of take-all was correlated with the nitrate nitrogen in the soil, and Stumbo *et al.* (13) have obtained good control of root-rot by the maintenance of available phosphorus and nitrate nitrogen content at suitable levels. In ordinary farming practice in the wheat belt of Australia, a good supply of available plant food in

the soil has been usually ensured by rotation of crops, fallowing, the application of phosphates and sometimes other fertilizers. As has been indicated by the widely varying response of the soils collected from different sources in and near Canberra to fertilizers and amendments, the specific needs of different districts, and soils in those districts in the wheat belt, might eventually be studied with profit.

Instances of failure to obtain control of take-all by the usual cultural methods may be due to naturally poor soils (9), soils exhausted by repeated cropping (7), to competition with weeds (16), to the leaching of available nutrients by heavy rains, to a limiting or sub-optimal supply of soil moisture during the growing season, or to a combination of two or more of these circumstances.

Sewell and Melchers (12), and Griffiths (7) state that repeated cropping of fields to wheat is usually followed by an increase in the economic importance of take-all. Exceptions are recorded by Fellows and Ficke (5), by the Waite Agricultural Research Institute (14), and in this paper. Some think that destructiveness of the disease is due directly to the building up of inoculum in the soil in the presence of the host plant, but if this were so it would be difficult to account for these exceptions and for the relative freedom from take-all in the continuous wheat plots at Rothamsted (10). The writer's experiments, however, show that impoverishment of the soil by repeated cropping is associated with increased susceptibility to the development of the disease. Clark (4) notes that in successive cropping take-all appears earlier in pots containing small amounts of soil than in those containing larger amounts. If the fertility of the soil is maintained by the regular addition of nutrients, and soil moisture is not a limiting factor*, little if any tendency is noted for the above-ground symptoms of take-all to appear. Soil collected from an area adjoining the site of the experiment here described, in which plants were badly affected with take-all in five successive seasons, was used to grow plants in drums, but the disease did not begin to re-appear until the fourth successive crop in the drums. Freedom from the disease in the drums is shown to be due to adequate water supply that allows the plants to make use of the store of available plant food in the soil. In drums in which the soil moisture, replenished by surface applications, is but little more than sufficient to keep plants growing, the appearance of the plants is the same as in the field in dry years, whiteheads being very common. *Ophiobolus graminis* is not easily isolated, but the cultures obtained indicate that the distribution of the organism is essentially the same in both the well-watered drums, and those that are almost wholly dependent upon rain water. In practice, therefore, control of take-all in areas or years in which soil moisture is not a limiting factor, depends on resistance to the development of the disease associated with proper nutrition. x

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* Unpublished work.

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The Effect of Potassium on the Growth of Subterranean Clover and Other Pasture Plants on Crawley Sand

1.—Pot-culture Experiments

By R. C. Rossiter, B.Sc. (Agric.),* and E. H. Kipps, B.Sc.*

Summary.

1. The results are given of two pot-culture experiments with Crawley sand at the Institute of Agriculture, Perth, Western Australia, in which responses to potash were obtained in the presence of phosphate, with Dwalganup and Mt. Barker subterranean clover.

2. Wimmera ryegrass, grown in association, gave responses to potash which were barely significant statistically.

3. Potassium deficiency symptoms appeared in the clover species more rapidly in the presence than in the absence of the grass.

4. Leaf-area measurements indicated no significant potash effects in the clover up to approximately 60 days from germination. Pronounced and significant effects were obtained one month later.

1. Introduction

The effect of mineral deficiencies on the growth of pasture plants is of particular importance in the south-west of Western Australia, where light-textured soils constitute the major portion of the area. Because subterranean clover is the most widely used pasture species, the nutritional problems relating to this plant merit special attention. That superphosphate has played an outstanding role in the establishment and productivity of this clover has been recognized for many years (Mursell, 1944). More recently, copper deficiency has been demonstrated (Jones and Elliott, 1944).

The investigations herein reported were carried out at the Institute of Agriculture, Perth. Profile details of the local soil type—Crawley sand—have been determined by one of the authors (Rossiter, 1938). Allied types occur in the Swan coastal plain (Teakle, 1938), so that the present studies may have more than immediately local application.

An experiment conducted in 1941 to examine the effects of various nutrients on a disease of lupins, since shown to be of virus origin (Norris, 1943), resulted in highly significant responses to potassium by subterranean clover which appeared as a volunteer species. A second trial in the following year failed to confirm this response. The two trials described below formed one phase of a more comprehensive investigation on the potassium problem. In the second part of the paper the results of field trials will be given.

2. Methods

Experiment 1.

Earthenware pots of 13.5 kg. capacity, the inner surface coated with paraffin wax, were used throughout. Seed of the Dwalganup variety of subterranean clover (*Trifolium subterraneum* L.) was germinated in yellow subsoil sand subsequent to inoculation by the admixture of a small amount of topsoil. Four seedlings were transplanted to each pot on May 21, 1943. Soil moisture was maintained

* An officer of the Division of Plant Industry.

within the range of 30–40 per cent. of the maximum water-holding capacity (8–10 per cent. actual moisture content). Distilled water was used for this and also the second trial.

Eight treatments were imposed in a $2 \times 2 \times 2$ factorial design with four replications, in a simple randomized arrangement. These treatments may be denoted by: O, P, K, Ca, PK, PCa, KCa, and PKCa, the actual quantities of salts employed being as follows:—

P- $\text{Na}_2\text{HPO}_4 \cdot 12\text{H}_2\text{O}$	..	..	..	2.7 g./pot*
K-KCl	..	..	..	1.0 g./pot
Ca- $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	..	..	..	13.6 g./pot

In addition, a basal nutrient mixture was added, consisting of—

Cu- $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	..	..	..	0.10 g./pot
Zn- $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	..	..	..	0.10 g./pot
Mn- $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$	..	..	..	0.17 g./pot
B- $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$	..	..	..	0.10 g./pot
Mo- NaHMoO_4	..	..	..	0.03 g./pot

The CaSO_4 was applied to the pots 10 days, and the remaining nutrients 1 day, before transplanting.

All plants were harvested at full flowering on September 7, 1943, and the tops oven-dried at 90°C . for 24 hours, for dry weight determinations.

The chemical analyses were carried out at Canberra.

Experiment 2.

Enamelled pots of relatively small capacity (1.50 kg.) were used in the second trial. Two species were tested, viz., subterranean clover (Mt. Barker variety) and Wimmera ryegrass (*Lolium rigidum* Gaud.). The clover seed was inoculated as before, and then sown directly into the pots, and with the grass seed where appropriate, on June 3, 1944. Emergence commenced on June 7, and six days later the seedlings were thinned out to four plants per pot with clover alone, and eight plants per pot—four of each species—where the grass was grown in association.

A basal dressing of $\text{Ca}(\text{NO}_3)_2$ was applied to all pots on June 16, and the differential nutrient treatments applied on June 19.

Altogether, 18 treatments were involved: the two nutrients, phosphorus and potassium, each at three levels, with and without Wimmera ryegrass grown in association with the clover. The scheme may be represented as follows:—

$$\left. \begin{matrix} \text{P0} \\ \text{P1} \\ \text{P2} \end{matrix} \right\} 3 \times \left. \begin{matrix} \text{K0} \\ \text{K1} \\ \text{K2} \end{matrix} \right\} 3 \times \left. \begin{matrix} \text{W0} \\ \text{W1} \end{matrix} \right\} 2$$

in which—

P1- $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$	..	..	..	0.139 g./pot†
P2- $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$	..	..	..	0.278 g./pot
K1-KCl	..	..	..	0.139 g./pot
K2-KCl	..	..	..	0.278 g./pot
W1-Wimmera ryegrass in association				

* On a surface-area basis 0.68 g./pot is equivalent to 1 cwt./acre.

† 0.139 g./pot is equivalent to 1 cwt./acre on a surface-area basis.

The basal dressing of $\text{Ca}(\text{NO}_3)_2$ was applied at 0.139 g. per pot to provide available nitrogen for the grass and to ensure an adequate calcium supply for the subterranean clover.

Each treatment was replicated five times in a randomized block lay-out.

On three occasions during the growing season—July 8, August 2, and September 1—total leaf area was estimated on each pot. For this purpose a rating technique (linear scale) was employed, based on a second degree polynomial regression equation relating total leaf area—determined by graphical means—to maximum width of central leaflet. The formula was calculated from measurements on 50 leaves of varying size. This method is similar to that used by Bald for potatoes (Bald, 1943). Although the rating scale was rather difficult to apply, the estimates were easily checked by direct measurement of leaflet width.

Harvesting took place on September 23, shortly before flowering was due to commence in the clover. The tops were carefully separated in the grass/clover mixture. All samples were then oven-dried and weighed as in Experiment 1.

3. Results

Experiment 1.

(a) *Total Dry Weight of Tops.*—A summary of the data is given in Table 1. Despite the wide range in mean values, intra-treatment variances were of the same order of magnitude and no transformation was used prior to analysis.

TABLE 1.—MEAN DRY WEIGHT AND EFFECT—SUBTERRANEAN CLOVER.

Treatment.					Dry Weight.	Effect.
					g./pot.	
O	..	..	..	..	5.03	—
P	..	..	..	..	9.16	+6.25**
K	..	..	..	..	5.07	+0.93
Ca	..	..	..	..	3.53	-2.01**
PK	..	..	..	..	13.34	+1.45*
PCa	..	..	..	..	9.00	+0.05
KCa	..	..	..	..	2.46	-1.17*
PKCa	..	..	..	..	9.58	+0.62
Standard error					±0.787	±0.557

** Significant at 1 per cent. level.

* Significant at 5 per cent. level.

The pronounced response to phosphorus was expected, and confirms earlier field-plot experiments. However, the depressing effect of CaSO_4 was quite unexpected; it will be discussed further at the end of the paper.

Examination of the interaction effects shows barely significant results for P x K and K x Ca. Of these the former was positive, suggesting that the effect of potassium was greater at high than at low levels of phosphorus; from the latter it appears that the depression in yield arising from CaSO₄ was greater in the presence than in the absence of potassium.

It should be mentioned here that a subsidiary contemporaneous experiment showed a significant depressing effect of the basal solution in the absence of phosphorus. This was demonstrated to arise from excess boron. Whether, as a consequence, interaction in the main trial was affected is not known.

(b) *Mineral Content of Tops.*—In Tables 2 and 3 are shown the results of these analyses; both absolute and percentage contents are presented.

TABLE 2.—RELATIVE AMOUNT (G./100 G.) OF MINERALS AND SOLUBLE ASH IN TOPS OF SUBTERRANEAN CLOVER.

Treatment.	Phosphorus.	Potassium.	Calcium.	Magnesium.	Sodium.	Nitrogen.	Sulphur.	Soluble Ash.
O ..	0.18	1.19	0.96	0.33	1.01	2.27	0.28	7.28
P ..	0.32	0.70	0.66	0.30	1.52	2.41	0.20	6.68
K ..	0.18	2.11	0.92	0.30	0.70	2.32	0.29	8.36
Ca ..	0.20	1.42	1.35	0.48	0.89	2.43	0.89	9.51
PK ..	0.31	1.40	0.71	0.30	1.11	2.41	0.20	7.20
PCa ..	0.31	0.79	1.16	0.44	1.24	2.33	0.82	8.46
KCa ..	0.18	2.53	1.26	0.45	0.50	2.57	0.91	10.06
PKCa ..	0.27	1.92	1.01	0.35	0.73	2.52	0.73	8.01

TABLE 3.—ABSOLUTE AMOUNT (MG./POT) OF MINERALS AND SOLUBLE ASH IN TOPS OF SUBTERRANEAN CLOVER.

Treatment.	Phosphorus.	Potassium.	Calcium.	Magnesium.	Sodium.	Nitrogen.	Sulphur.	Soluble Ash.
O ..	9	60	48	17	51	114	14	366
P ..	29	64	60	27	139	221	19	612
K ..	9	107	47	15	35	118	15	424
Ca ..	7	50	48	17	31	86	31	336
PK ..	41	187	94	40	148	321	27	961
PCa ..	28	71	103	40	112	210	74	761
KCa ..	4	62	31	11	12	63	22	247
PKCa ..	26	184	97	33	70	241	70	267

Two general types of response can be distinguished:—

(1) Where addition of nutrient X tends to give a considerable increase in the relative amount of that nutrient. Where this addition also leads to an increase in yield there is obviously a relatively greater

increase in absolute amount of X (e.g. phosphorus $O-P$, $K-PK$, $Ca-PCa$, $KCa-PKCa$; potassium $P-PK$, $PCa-PKCa$). Where there is no effect on yield, the increase in absolute amount is naturally proportionate (e.g. potassium $O-K$, and as border line cases $PCa-PKCa$, $Ca-KCa$; calcium $P-PCa$). Where the addition of nutrient X actually decreases yield, the absolute amount of X may change only slightly (e.g. potassium $Ca-KCa$; calcium $O-Ca$, $PK-PKCa$) or it may be actually depressed (e.g. calcium $K-KCa$).

(2) Where addition of nutrient X may have a variety of effects on the relative and absolute amounts of nutrient Y . Where growth is increased by X there is a tendency for the relative amount of Y to be decreased. This is doubtless a partial explanation of the effects of phosphorus on the relative amounts of potassium, calcium, magnesium, sulphur, and soluble ash. The effect on potassium, however, is complicated by the fact that phosphorus was applied as Na_2HPO_4 —the interaction diagrams for relative amounts of potassium and sodium are almost exact mirror images—and high sodium in the medium has depressed the intake of potassium.

The effect of Ca on relative amount of magnesium is striking. (In this instance growth is decreased by X and the relative amount of Y increased.) A similar example of positive correlation between calcium and magnesium percentages has been reported for lucerne (Hunter *et al.*, 1943).

The effect of P on total nitrogen content is also of interest. In the absence of Ca , P resulted in an increase in relative amount of nitrogen, which is in keeping with other work on legumes (e.g. Teakle, 1945). However, the fact that the relative amount of nitrogen was decreased with P in the presence of Ca is suggestive of toxic effects of the latter.

Since this paper is primarily concerned with potassium nutrition, it is advisable to emphasize the importance of the decrease in relative content of potassium when phosphorus is applied (both in the presence and absence of Ca). In the absence of K the increased yields with P caused a slightly greater absolute amount of potassium in the tops.

Experiment 2.

(a) *Total Dry Weight of Tops*.—In this and the following section a logarithmic transformation has been used wherever the data are treated statistically.

(1) *Subterranean clover*.—Highly significant treatment effects were obtained for P , K , W , PK , and PW . A summary of the data is given in Table 4.

The significant depressing effect of the associated grass on the yield of clover was, of course, to be expected. Of some interest also is the $P \times W$ interaction. Examination of the data will show that the mean relative decrease in yield due to Wimmera ryegrass was significantly higher at P_0 than at P_1 and P_2 . Taken in conjunction with the evidence on Wimmera ryegrass in Table 5, this probably reflects a differential species response to phosphorus, the clover responding more markedly than Wimmera ryegrass.

TABLE 4.—MEAN DRY WEIGHTS (G./POT) OF SUBTERRANEAN CLOVER, AS AFFECTED BY SUPPLY OF PHOSPHORUS AND POTASSIUM AND ASSOCIATED GROWTH OF WIMMERA RYEGRASS.

Without Wimmera (W0).

—	P0.	P1.	P2.	Mean.
K0 ..	1.207 (2.0818)	2.631 (2.4202)	2.542 (2.4052)	2.006 (2.3024)
K1 ..	1.416 (2.1510)	3.314 (2.5204)	3.286 (2.5166)	2.489 (2.3960)
K2 ..	1.385 (2.1412)	3.399 (2.5314)	3.391 (2.5304)	2.518 (2.4010)
Mean ..	1.332 (2.1247)	3.095 (2.4907)	3.049 (2.4841)	2.326 (2.3665)

With Wimmera (W1).

—	P0.	P1.	P2.	Mean.
K0 ..	0.517 (1.7138)	1.336 (2.1256)	1.172 (2.0690)	0.932 (1.9695)
K1 ..	0.511 (1.7084)	1.675 (2.2240)	1.589 (2.2010)	1.108 (2.0445)
K2 ..	0.472 (1.6740)	1.792 (2.2532)	1.715 (2.2342)	1.132 (2.0538)
Mean ..	0.500 (1.6987)	1.588 (2.2009)	1.472 (2.1681)	1.053 (2.0226)

Average W0 and W1.

—	P0.	P1.	P2.	Mean.
K0 ..	0.790 (1.8978)	1.875 (2.2729)	1.726 (2.2371)	1.368 (2.1359)
K1 ..	0.850 (1.9297)	2.356 (2.3722)	2.284 (2.3588)	1.661 (2.2202)
K2 ..	0.808 (1.9076)	2.468 (2.3923)	2.412 (2.3823)	1.689 (2.2274)
Mean ..	0.816 (1.9117)	2.217 (2.3458)	2.118 (2.3261)	1.565 (2.1945)

Standard errors: mean of 5—(0.0229)
 10—(0.0162)
 15—(0.0132)
 30—(0.0093)

Note.—The non-bracketed figures are geometric means of the original observations. Figures in parentheses are mean log. $\times 10^3$.

As in Experiment 1 the response to phosphorus was highly significant. However, at the P2 level, yields were slightly, though significantly, less than at P1.

The P $\times$ K interaction is exhibited more clearly in this trial than in the first. In the absence of phosphorus no beneficial effects of any magnitude followed on the application of potassium. In its presence yields were increased significantly over and above those obtained with phosphorus only. Averaging P1 with P2 and K1 with K2, the actual and relative mean yields were—

Control.	P only.	K only.	P + K.
0.865	1.920	0.942	2.531
100	222	109	293

Bearing in mind the greater variability in the first trial, and also differences in strain and time of harvest, the relative yields for each experiment are in close agreement.

(2) *Wimmera ryegrass*.—Mean values are given in Table 5. The trends are obviously similar to the trends of subterranean clover yields. The interaction component is significant in the 2 x 2 table formed by K0P0, and the means obtained by grouping K1 with K2 and P1 with P2. With increased amounts of P at all levels of K there is an increased yield. On the other hand there is a significant response to K only in the presence of P1 and P2.

TABLE 5.—MEAN DRY WEIGHT (G./POT) OF WIMMERA RYEGRASS AS AFFECTED BY PHOSPHORUS AND POTASSIUM SUPPLY.

—	P0.	P1.	P2.	Mean.
K0 ..	0.720 (1.8562)	0.905 (1.9568)	1.085 (2.0354)	0.890 (1.9495)
K1 ..	0.773 (1.8882)	1.212 (2.0832)	1.404 (2.1472)	1.095 (2.0395)
K2 ..	0.705 (1.8484)	1.275 (2.1054)	1.335 (2.1252)	1.063 (2.0263)
Mean ..	0.731 (1.8642)	1.118 (2.0485)	1.267 (2.1026)	1.012 (2.0051)

Standard errors: mean of 5—(0.0331)
15—(0.0191)

Note.—Figures in parentheses are $\log \times 10^3$ as in Table 4.

(b) *Changes in Leaf Area of Subterranean Clover*.—Since a large number of pots are required for the determination of changes in dry weight with time, especially for a large number of treatments, it was decided to use leaf areas as indices of ontogenetic change. Total leaf area on any given occasion is an index of the capacity of the plant to produce dry matter in the immediate future. In early stages of growth, however, there tends to be a strong correlation between leaf area and total yield, though this may not be relied upon to the extent of using the former as a strict index of the latter. In any case, leaf area data are of considerable value on their own account.

In the present trial measurements were made on three occasions. Results are shown in Fig. 1.

On the first occasion, 41 days after germination, the P treatments only showed highly significant differences; both P1 and P2 were greater than P0, the increase being of the order of threefold. The main effect of P therefore took place prior to this occasion.

At day 57 this increase with P was almost identical in magnitude, whilst the associative effect of *Wimmera ryegrass* had now produced a highly significant depression in leaf area.

The P and W responses were still predominant at day 87, but highly significant effects due to potassium and its interaction with P and W (both singly and together) had now become obvious. It should be mentioned that at day 57 a barely significant P x W interaction was detected, the decrease in leaf area with *Wimmera* present being greater at P2 than at P0. The day 87 figures indicate that this was influenced largely by the relatively great difference at K0.

Stated in another way, the response to potassium with phosphorus present was relatively greater when the clover was grown in association with *Wimmera ryegrass*.

This second order interaction appears to be due entirely to an effect on leaf area, as such. Analysis of the data for total number of leaves at day 87 showed no effect of either K or P x K, although a significant increase and decrease to P and W respectively. Premature senescence of the older leaves accounted for the lack of increase in total leaf areas between t_2 and t_3 in P1W1 and P2W1; the fact that the P x K x W interaction for total dry matter was not significant may be at least partially accounted for, then, in terms of higher leaf dry weight to area ratios in the treatments mentioned.

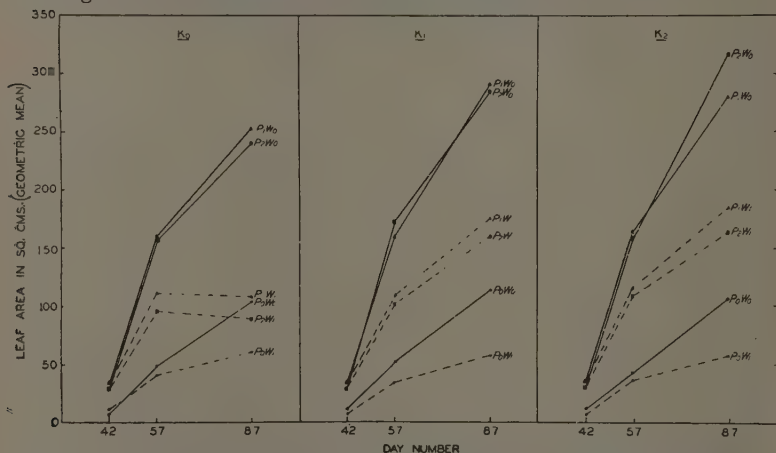


FIG. 1.—Showing the effect of potash, phosphorus, and presence and absence of Wimmera ryegrass on the changes in total leaf area of subterranean clover.

Relative leaf-growth rates were calculated using the equation

$$R_{LA} = \frac{\log e L_{A_2} - \log e L_{A_1}}{t_2 - t_1}, \text{ where } L_A = \text{leaf area in sq. cm., and}$$

t = time in days.

TABLE 6.—RELATIVE LEAF GROWTH RATES (SQ.CM./SQ.CM./DAY) OF SUBTERRANEAN CLOVER, AS AFFECTED BY PHOSPHORUS AND POTASSIUM SUPPLY, AND ALSO ASSOCIATED GROWTH OF WIMMERA RYEGRASS.

			Occasion 1-2.			Occasion 2-3.		
			K0.	K1.	K2.	K0.	K1.	K2.
P0W0	..	..	0.104	0.107	0.098	0.028	0.027	0.030
P0W1	..	..	0.081	0.088	0.089	0.017	0.018	0.014
P1W0	..	..	0.106	0.107	0.106	0.015	0.020	0.018
P1W1	..	..	0.082	0.086	0.082	0.001	0.016	0.015
P2W0	..	..	0.106	0.114	0.108	0.014	0.017	0.023
P2W1	..	..	0.076	0.085	0.092	0.002	0.115	0.014

Relative leaf growth rates were everywhere depressed by *Wimmera* ryegrass, the depression being relatively greater between t_2 and t_3 : the latter would be in keeping with progressive competition between grass and clover.

The effects of both phosphorus and potassium were only slight between t_1 and t_2 . Between t_2 and t_3 , however, there was a fairly consistent decrease in relative leaf growth rate from P0 to P2; in the presence of *Wimmera* ryegrass this was extremely pronounced at K0, yet inappreciable at K2. Although the P1K0W1 and P2K0W1 figures were determined primarily by premature leaf senescence, the general effects of the phosphorus treatments is not so readily understood. No satisfactory explanation can be put forward.

4. Discussion

The first point arising from the data has to do with the depressing effect of high CaSO_4 levels on growth. Although it is conceivable that the high relative amount of calcium may have reduced phosphorus uptake as suggested by the work of Shih (see Richards, 1941), a more likely explanation is that toxic effects were produced. It will be noted (*vide* Table 2) that the total sulphur content in the CaSO_4 treatments was of the order of 0.8 per cent. (on a dry matter basis). Since the actual sulphate sulphur constituted almost 80 per cent. of this amount, it may well be that the plants were adversely affected by toxicity of the SO_4 ion. Eaton (1942) has shown that such toxic effects may depress growth gradually without any obvious external symptoms*. There is one further possibility, viz., that soil pH was reduced sufficiently to affect plant growth. Supporting data are scanty: it has been shown that CaSO_4 at the rate of 30 cwt. per acre, in the absence of phosphorus, will reduce the pH of Crawley sand from 6.2 to 5.3.

That a P $\times$ K yield interaction occurs with subterranean clover on the soil herein studied appears reasonably well established; indeed, further evidence on this point will be presented in Part 2 of this paper. No such interaction was present in the leaf-area data of experiment 2 up to approximately 60 days from germination, so that potassium supply presumably was not limiting during early growth.

Now the exchangeable K in the Crawley sand is of the magnitude of 0.06 m.e. per 100 g., so that the total exchangeable K per pot for experiments 1 and 2 was 316 mg. and 35 mg. respectively. For the former trial the quantity of exchangeable soil potassium should have been more than adequate to account for the absolute potassium content of the highest yielding treatment (PK), and in the second trial, almost adequate. The following tentative explanation is therefore put forward. During the first few weeks, when the growth rate was low, the rate of supply of exchangeable K from the soil was adequate for normal metabolic functions, even where P was not limiting. At a later stage, when the growth rate was relatively higher on all treatments, the rate of supply of soil K became limiting with high P but not with low P. Of the two nutrients, P was more deficient in the soil than K.

* It is of interest to calculate the relative SO_4 content of lucerne—the only legume studied—in relation to yield depressions. With a 28 per cent. reduction (on the first cut) the SO_4 content was of the order of 1.2 g./100 g. dry matter. This figure was exceeded in experiment 1.

The position with respect to Wimmera ryegrass is less precise. In the second experiment reported no significant P x K interaction was detected.* This, of course, may have been influenced by the associated effect of the legume, yet the likelihood of a difference in pattern of reaction in the case of grasses is suggested by a pot-culture experiment carried out in conjunction with experiment 1. Perennial veldt grass (*Ehrharta calycina* Sm.) was subjected to the following treatments:—N, P, K, and Ca in a 2⁴ factorial design. The only significant effects on total yield were N, P, and the N x P interaction. Chemical data suggest that the grass is capable of tolerating a lower relative amount of potassium than subterranean clover without serious detriment to growth; the mean potassium content of the N-No K plants at the flowering stage was 0.71 per cent. Nevertheless, P x K interactions may occur in grass species, as the work of Verma (quoted by Gregory, 1937) has clearly demonstrated.

A description of the potassium deficiency symptoms observed in the experiments is not intended, since a section of the second part of this paper will be devoted to a comprehensive account of this aspect of the problem.

5. Acknowledgments

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* By grouping the two phosphate levels, P1 and P2, the P x K interaction was found to be significant, though barely so.

The Effect of Potassium on the Growth of Subterranean Clover and Other Pasture Plants on Crawley Sand

2.—Field-plot Experiments

By R. C. Rossiter, B.Sc.(Agric.) *

Summary.

1. The results of field-plot trials, with potash fertilizers, are presented and discussed, and deficiency symptoms in subterranean clover are described in detail.

2. Of the species examined, only one—subterranean clover—showed clearly defined responses to potassium. Wimmera ryegrass responses were small and of doubtful significance, whilst the W.A. lupin, perennial veldt grass, and capeweed, showed either no increase in yield or a slight depression through inter-specific competition with the clover.

3. Seed production in subterranean clover was adversely affected by low potassium supply.

4. Potassium-deficient leaves of subterranean clover showed a high relative content of sodium, but no excessive concentration of calcium, despite the high exchangeable Ca status of the soil type studied.

1. Introduction

Evidence from pot trials has been presented of increased yields of subterranean clover (*Trifolium subterraneum* L.) with potassium, in the presence of phosphate on Crawley sand (Rossiter and Kipps, 1947). Furthermore, the association of an annual grass Wimmera ryegrass (*Lolium rigidum* Gaud.) did not materially affect the magnitude of this response, although deficiency symptoms in the legume appeared earlier.

The range of plant species is rather wider in the present trials—a point of obvious importance—yet it should be borne in mind that inter-specific competitive effects may have masked real potassium effects on the species. The point is of rather academic interest, since under field conditions subterranean clover almost without exception is the basic constituent of sown pastures in the south-west of Western Australia.

The potassium deficiency symptoms are described fully with the belief that they will enable recognition of potassium deficiency in subterranean clover elsewhere in southern Australia.

2. Preliminary Trial

(1) General.

Descriptions of experimental procedure for each individual trial would occupy undue space, and general methods can, in any case, be inferred from the detailed information of the main trial (see below). All trials were carried out in small plots whose dimensions varied from 10 links by 10 links up to 30 links by 15 links, each trial being limited to a very small acreage. To determine seed yield in subterranean clover, duplicate square link soil samples were taken from each plot to a depth of 3 in., the material sieved, and burr formed

* An officer of the Division of Plant Industry.

during the current season carefully separated from the residue. Seed yields were calculated from the regression equation of seed weight on burr weight. Although it is recognized that the sampling ratio was extremely small, significant differences were found in a number of cases.

Experiment 1 was carried out in 1941 and had as its primary objective the study of the effects of potassium, copper, and chromium, in a $2 \times 2 \times 2$ factorial design, on the incidence of a disease in the W.A. lupin (*Lupinus pilosus* Murr. var. *Cosentini* Guss.). Towards the end of the growing season, treatment effects were observed in the volunteer pasture of Dwalganup subterranean clover/Wimmera ryegrass which established beneath the lupin crop. The pasture was therefore harvested for yield determinations.

In Experiment 2, conducted in 1942, the effect of varying levels of potassium was studied on a mixed Dwalganup subterranean clover/Wimmera ryegrass pasture established in 1940 and top-dressed in 1940 and 1941 with superphosphate only. In contrast to the first trial, fertilizers were applied without early surface cultivations and in consequence effective germination occurred earlier.

After analysis of the results of Experiments 1 and 2, it was decided that two further trials should be conducted on the same sites, but with reversed pre-fertilizer treatment. Experiment 3 occupied the original site of Experiment 1, with the differences (a) that a new set of potassium treatments was allotted at random to the previous Cu and Cr treatments (to which no yield responses were observed in 1941), and (b) that no soil cultivation treatments were imposed. The trial was conducted in 1944, having remained open to uniform continuous grazing during 1943.

Experiment 4 was carried out on the site previously occupied by Experiment 2, and in the same year as the third trial, viz., 1944. It differed, again, in two respects from Experiment 2: (a) a new set of potassium treatments was applied to all plots by making use of the split-plot technique, and (b) the whole experimental area was rigorously cultivated prior to application of the potash fertilizers.

In each of the four trials superphosphate was applied at the rate of 2 cwt. per acre as a uniform basal dressing.

(ii) Results.

(a) *Herbage Dry Weight Yields.*—In Experiment 1 no differences resulting from the application of either copper or chromium were significant. Potassium, however, produced a highly significant response in the case of subterranean clover, whilst with Wimmera ryegrass the increase in yield was barely significant at the 5 per cent. level (see Table 1). The yields of lupins and miscellaneous species were significantly depressed, presumably by competitive effects of the clover.

The relative magnitude of the response of subterranean clover was much the same in Experiments 1 and 3 in spite of the high yields of miscellaneous species in the latter.

The response of Wimmera ryegrass, though consistent in each experiment, was not significant even at the 5 per cent. level in Experiment 3. Miscellaneous species—chiefly capeweed—showed an insignificant reduction in yield with potassium in the third trial. Expressed

as a percentage of total yield, however, capeweed was diminished from 53 per cent. to 41 per cent. by potassium, this reduction being significant at the 1 per cent. level.

TABLE 1.—MEAN YIELDS OF DRY MATTER (CWT./ACRE).
($K = KCl$ at 1 cwt./acre.)

Species Group.	Experiment 1 (1941).			Experiment 3 (1944).		
	No K.	K.	S.E.	No K.	K.	S.E.
Subterranean clover ..	15.02	25.35	1.115	6.33	9.70	0.649
Wimmera ryegrass ..	1.27	2.01	0.177	3.22	3.83	0.417
Miscellaneous species*	2.45	1.13	0.216	13.35	11.37	0.923
Lupins	82.18	69.88	2.644	..	..	..
Total, minus Lupins	18.74	28.49	1.151	22.90	24.92	0.857

* Miscellaneous species in 1941—*Trifolium procumbens* L., *Tunica prolifera* L., *Briza maxima* L.
In 1944—*Cryptostemma calendulaceum* (L.) R. Br., *Vulpia Myuros* L., *Ehrharta longiflora* Sm.

In Experiment 2 no significant responses to potassium were detected, the mean yields for subterranean clover and Wimmera ryegrass being 9.6 ± 1.48 cwt. per acre and 11.8 ± 1.71 cwt. per acre respectively.

Analysis of the split-plot latin square design of Experiment 4 revealed highly significant main plot differences for "columns," and also a barely significant increase in yield of subterranean clover due to potassium applied to the sub-plots in 1944. The relative responses of the clover to the fertilizer in the several "columns" were as follows:—

A	B	C	D	E
+ 41%	+ 25%	+ 5%	— 5%	+ 4%

This soil fertility trend was not apparent in the 1942 data, and it is possible that the cultivation treatments of 1944 influenced the nature of the responses to potassium. In any case, it may be noted that the magnitude of the response in "column" A is comparable with those of Experiments 1 and 3.

(b) *Seed Yields of Subterranean Clover.*—Analysis of data obtained from Experiment 3 indicated a highly significant effect of potassium on seed production. The relevant yields (together with total tops) were:—

—		No K.	K.	S.E.
		cwt./acre.	cwt./acre.	
Seed	..	2.87	3.96	0.212
Herbage	..	6.33	9.70	0.649

The relative increase in seed yield was therefore not as pronounced as that in herbage. Whether this difference was real is not known, but the errors in sampling technique for seed production may conceivably account for part of the discrepancy. In this regard it may be pointed out that seed yields, even in the presence of potassium, were low: figures of the order of 10 cwt. per acre are not infrequently obtained on Crawley sand with this clover.

A more comprehensive analysis of the effects of acute potassium deficiency on clover seed is shown in Table 2. This information was collected from a separate experiment, not previously considered.

TABLE 2.—THE EFFECT OF EXTREME POTASSIUM DEFICIENCY ON SEED AND BURR CHARACTERS IN DWALGANUP SUBTERRANEAN CLOVER.

Variate.	No K.	K.
No. burrs per sq. link	40.3	221.2
Total burr wgt.—g./sq. link .. .	1.3	13.6
Wgt. per burr—mg.	32	68
Seed yield—cwt./acre	1.2	12.1
Wgt. per seed—mg.	5.2	8.5
No. seeds per burr	2.8	3.5
Ratio seed wgt. to burr wgt. .. .	0.46	0.45

The striking decrease in seed yield on the No K plot can be accounted for largely by the smaller number of burrs produced. Although the mean weight per burr under potassium deficiency was approximately one-half that of the plants on the manured plot, the ratio of seed weight to burr weight was almost unaffected by potassium supply. The constancy of the ratio is determined by the smaller weight per seed and the lower number of seeds per burr under potassium-deficient conditions. (Confirmation of the reduction in weight per seed was obtained from Experiment 3 where K and No K values were 6.6 mg. and 5.0 mg. respectively.)

3. Main Trial

(i) Procedure.

The site was cleared from virgin forest in 1943 and twice cultivated after the opening autumn rains of 1944 to provide a satisfactory seed-bed. The experiment area was pegged out on May 10, 1944, and comprised 90 plots each 10 links square. A seeds mixture of Dwalganup subterranean clover and perennial veldt grass (*Ehrharta calycina* Sm.) at the rates of 12 lb. per acre and 4 lb. per acre respectively was sown uniformly over the area, using sawdust as a matrix to provide adequate bulk and even distribution. A shallow soil covering was ensured by hand raking.

Seedling emergence was first observed on May 23.

Eighteen treatments were distributed in a factorial randomized block design with five replications, the treatment scheme being as follows:—

$$\left. \begin{matrix} P0 \\ P1 \\ P2 \end{matrix} \right\} 3 \times \left. \begin{matrix} K0 \\ K1 \\ K2 \end{matrix} \right\} 3 \times \left. \begin{matrix} M0 \\ M1 \end{matrix} \right\} 2$$

where—

$$\begin{array}{lll} P1 & \dots & \dots \text{ 2 cwt./acre superphosphate.} \\ P2 & \dots & \dots \text{ 4 cwt./acre superphosphate.} \\ K1 & \dots & \dots \text{ 1 cwt./acre KCl.} \\ K2 & \dots & \dots \text{ 2 cwt./acre KCl.} \\ M1 & \dots & \dots \left\{ \begin{array}{l} 15 \text{ lb./acre MgSO}_4. \\ 5 \text{ lb./acre CaSO}_4. \\ 5 \text{ lb./acre ZnSO}_4. \end{array} \right. \end{array}$$

All fertilizer treatments were applied on June 30, 1944, the manures being mixed previously with yellow subsoil sand to provide uniform distribution.

Since the growth of clover was poorer than expected at the conclusion of the first season, yield estimations were made by eye on a 0-10 rating basis.

No fertilizers were applied in 1945. The plots were sampled at the end of this season with a hand-operated shearing machine, using a 25 sq. link sample per plot. Harvested material was air-dried and stored prior to hand separation for estimation of botanical composition and yield of components. Dry weights were obtained by the usual method of oven-drying at 95°C. for 24 hours.

(ii) *Results.*

(a) 1944.—No differences of any consequence appeared until ten weeks after germination (July 28), when phosphate effects were easily distinguished. After a further four weeks (viz., at the end of August) differences due to potassium were noted in the growth of subterranean clover, which by this time had reached the flowering stage. All treatment effects became progressively marked throughout September, and estimated productivity was determined at the end of this month.

Neither perennial veldt grass nor miscellaneous species—chiefly *Tunica prolifera* (L) Scop., *Briza maxima* L., and *Hypochaeris glabra* L.—showed any response to fertilizer treatments; the data for Dwalganup subterranean clover only are presented in Table 3 below.

TABLE 3.—MEAN PRODUCTIVITY RATINGS—DWALGANUP SUBTERRANEAN CLOVER—SEPTEMBER 30, 1944.

		P0.	P1.	P2.	Mean.
K0	..	0.50	2.90	2.55	1.98
K1	..	0.55	7.30	8.70	5.52
K2	..	0.55	7.70	9.00	5.75
Mean	..	0.53	5.97	6.75	4.42

S.E. main effects—0.2006.

Treatment variances were relatively constant, and the analysis was performed on the original data. Since the mixed fertilizer treatment produced extremely small and insignificant effects, the summary table relates only to phosphorus and potassium, in which main effects and P x K interaction were all highly significant. This latter finding is in substantial agreement with results previously reported (Rossiter and Kipps, 1947) using the pot-culture technique. Superphosphate alone increased yields from five- to six-fold, whilst potassium, in addition to superphosphate, produced an increase in yield of the order of three-fold compared with the P-No K treatments. Obviously in this trial the area selected was acutely deficient in potassium (cf. data of Table 1).

Mention should be made of occasional localized effects within plots. A number of instances were noted on portions of P and PM plots where the production of clover was abnormally high and the plants without

symptoms of potassium deficiency. Such areas were associated with old tree stump sites and have been frequently observed on Crawley sand. Anderson (1942) has reported somewhat similar effects from wood-ashes in the Meadows district of South Australia, which were attributed to molybdenum. In the present instance unpublished data suggest that the effect is due almost solely to potassium contained in the wood-ash.

(b) 1945.—Shortly after germination (May 1) of the subterranean clover in the second year, it was observed that the legume was almost absent on the No P plots, and that seedling density on the P-No K plots was very much lower than where both fertilizers had been applied in 1944. The former discrepancy in seedling establishment explains the extreme difference in yield between No P and P-No K treatments (see Table 4); the second is in keeping with the results shown in Table 2.

Differences between P and PK treatments were clearly obvious in the clover at the commencement of flowering—early August—and, as in 1944, became progressively greater thereafter.

TABLE 4.—MEAN YIELDS OF DRY MATTER (CWT./ACRE)—OCTOBER 14, 1945.

(Average of *M* and No *M* treatments.)

Treatment.	Subterranean Clover.	Perennial Veldt Grass.	Miscellaneous Species.	Total.
0 ..	trace	3.18	0.67	3.85
P1 ..	2.62	8.26	0.53	11.41
P2 ..	2.11	8.58	0.72	11.41
K1 ..	trace	2.58	0.93	3.51
K2 ..	0.07	2.70	0.90	3.67
P1K1 ..	5.93	7.87	0.33	14.13
P1K2 ..	6.55	7.25	0.30	14.10
P2K1 ..	10.81	8.16	0.28	19.25
P2K2 ..	12.02	8.82	0.37	21.21

The beneficial effects of phosphate on perennial veldt grass were shown throughout the growing season. In the previous paper (Rossiter and Kipps, 1947) it was stated that a highly significant N x P interaction occurred with this grass in a pot-culture experiment; in actual fact there was practically no response to phosphorus in the absence of applied nitrogen, yet in its presence the yield was increased by approximately 30 per cent. Since there is adequate observational evidence that even a single year's growth of subterranean clover increased markedly the yield of non-leguminous pasture species in this State, the differential response of *Ehrharta calycina* to phosphate in the two seasons 1944 and 1945 of the present trial may conceivably be accounted for by an increased soil N status following on the growth of clover in the first season (1944). Furthermore, the absence of any response to potassium in either year of this main experiment confirms evidence from the pot-culture trial already referred to.

Low yields for the miscellaneous species group with the PK treatments reflect competition from the perennial grass and clover.

The three botanical separation groups already considered are explanatory of the "total" column of Table 4. One point of interest may be mentioned briefly: with superphosphate alone the clover contributed only 20 per cent. of the total yield, whereas with phosphate plus potassium—more particularly the higher level of the former fertilizer—the figure was increased to approximately 50 per cent.

During the 1945 season, treatment replicates were more variable than usual with trials on Crawley sand—a fact which may have been due, in no small degree, to a combination of two factors: (a) small plot size, and (b) recency of clearing. In any case the original data were transformed for purposes of statistical analysis.

TABLE 5.—THE INTERACTION EFFECT OF SUPERPHOSPHATE AND POTASSIUM ON DWALGANUP SUBTERRANEAN CLOVER AND PERENNIAL VELDT GRASS—1945.

$$\text{Variate} \begin{cases} \text{Clover} = \log ((\log x + 1) + 1). \\ \text{Veldt grass} = \sqrt{x}. \end{cases}$$

Subterranean Clover.

—		P0.	P1.	P2.	Mean.
K0	..	..	0.3536	0.3118	0.2218
K1	..	..	0.4546	0.4992	0.3179
K2	..	0.0310	0.4616	0.5022	0.3316
Mean	..	0.0103	0.4233	0.4377	0.2905

S.E. main effects—0.0124.

Body of table—0.0215.

Perennial Veldt Grass.

—		P0.	P1.	P2.	Mean.
K0	..	6.070	10.087	10.193	8.783
K1	..	5.380	9.917	10.059	8.452
K2	..	5.612	9.187	10.454	8.418
Mean	..	5.687	9.730	10.235	8.551

S.E. main effects—0.321.

Body of table—0.556.

Analysis of variance for each set of data demonstrated that the mixed fertilizer produced no significant effects, thus confirming the 1945 observational evidence and also the 1944 results; they are not shown separately in either Table 4 or 5.

For subterranean clover, the main effects for both P and K were significant at the 1 per cent. level, and the P x K interaction significant at the 5 per cent. level. Despite the fact that the increase in yield from P1 to P2 in the presence of K was not significant on the transformed data, it is difficult to conceive that the increase was not actually a real one.

Similarly with *Ehrharta calycina* there was a consistent increase from P1 to P2, which did not reach significance in the analysis of variance. Moreover, the depression in yield with K1 is suggestive of a real competition effect from the clover, even though the effect could not be substantiated by statistical analysis. However, there is no question of the significance of the previously mentioned increase in yield of perennial veldt grass to phosphate.

4. Diagnosis of Potassium Deficiency in Subterranean Clover

(i) *Description of Deficiency Symptoms.*

The following details apply specifically to the Dwalganup strain; Mt. Barker has been examined only cursorily, but appears to follow similar lines.

Where the deficiency is not acute, external symptoms are rarely exhibited until shortly before the flowering stage; in the case of mild or incipient deficiency, symptoms may be delayed almost until maturity. The first sign of deficiency is a slight bronzing of the upper portion of the older leaflets, i.e., above the crescent. Very shortly afterwards—sometimes coincidentally—reddish-brown spots appear on the leaf surface; these are aptly described as “stained” areas, and are frequently 1 mm. to 3 mm. in diameter. Closer inspection of these areas usually reveals the presence of a central area of surface “pitting” which seldom becomes extensive. Gradually, the leaf surface becomes chlorotic, particularly above the crescent, and marginal necrosis or “die-back” follows.

Plants exhibiting mild deficiency symptoms appear almost normal in a number of respects, viz., leaf area, tillering, and growth rate. In this they resemble potassium deficiency as described by Richards and Templeman (1936) in the barley plant. Reduction in dry weight then, according to these authors, depends on—

- (1) reduction in leaf area—by early death of leaves; and
- (2) much reduced photosynthetic activity of living leaves.

Decreases in total dry weight not infrequently may be exceedingly difficult to demonstrate in subterranean clover, especially where symptoms are of the incipient type and consequently tardy in development.

Where potassium deficiency is acute, symptoms differ in a number of respects from those described above. Symptoms may be observed as early as six weeks after germination—very rarely before this time; they commence with an ashy-grey to reddish-brown “pitting” on the surface of the older leaflets, the “pitted” areas measuring from 0.5 to 1 mm. in diameter. The necrotic tissue so produced conforms closely in anatomical characters to that described for red clover (Lindenbein, 1936). The leaves in which “pitting” occurs may be normal in colour, or even a slightly darker green than normal, but quickly develop a mild yellowish-green chlorosis.

The most striking character of acute deficiency appears in the youngest leaves developed very shortly after the above-mentioned symptoms have become well-defined. No obvious reduction in leaf-area is noticed in the older affected leaves, yet these young leaves are greatly reduced in size. Moreover, they are dark green in colour, possess a

puckered surface, and may show a mild mosaic-like chlorosis. There can be no doubt that a drastic physiological derangement takes place at this stage. The number of small dark-green leaves continues to increase, and at the same time the older affected leaves develop marginal necrosis and quickly senesce while leaves of only slightly younger age develop "pitting" and mild chlorosis.

Normal tiller elongation does not take place, and consequently the plant develops a rosette-like habit. At flowering, many of the older leaves have died, and the small dark-green leaves are particularly conspicuous. They occur for the most part on extremely short tillers close to the central axis of the plant; some, however, are found on moderately elongated tillers but are confined to the mid-region, leaves at both the base and tip of the tiller being much less reduced in size and almost normal in colour. Eventually, the small leaves show some pitting and develop marginal necrosis, but the retrogressive changes take place at a much slower rate than in the larger leaves.

Reduction in plant dry weight is, of course, more obvious in acute deficiency and includes, in addition to the two causes mentioned by Richards and Templeman (*loc. cit.*), the effect of reduced size of individual leaves. Not infrequently affected plants may die outright long before those normally fertilized with potassium. Almost invariably they are extremely stunted and produce only small seed yields.

(ii) *Mineral Status of Deficient Herbage.*

From evidence presented in the first part of this paper (*loc. cit.*) the relative amount of potassium in the tops of deficient plants was of the order of 0.7 per cent. A summary of results for leaf, and leaf + petiole samples collected in the field is given in Table 6. It will be noted that, even in the absence of external symptoms, potassium concentrations are not high: healthy leaves (and leaves + petioles) contain approximately 0.9 per cent. K. Furthermore, from other studies on Crawley sand, application of potash fertilizer seldom raises the level of potassium much beyond 1.5 per cent. during the month samples have usually been collected, viz., September.

TABLE 6.—RELATIVE AMOUNT OF POTASSIUM (PER CENT. DRY WEIGHT) IN SELECTED SAMPLES OF DWALGANUP SUBTERRANEAN CLOVER.

Date Collected.	Description.	Percentage K.
Sept. 15, 1943 (leaf + petiole) ..	(a) Healthy	0.93
	(b) Leaves showing chlorosis and marginal necrosis	0.56
Sept. 28, 1944 (leaf only) ..	(a) Healthy	0.93
	(b) Symptoms identical with 1943 (b) ..	0.38
Sept. 19, 1945 (leaf only) ..	(a) Healthy	0.88
	(b) Leaves showing slight bronzing and small reddish-brown stained areas (mild deficiency)	0.44
	(c) Leaves very small, mostly dark-green, but sometimes with mild chlorosis (acute deficiency)	0.36

In Dwalganup subterranean clover the stem fraction is some 30 per cent. higher in potassium than the leaf (unpublished data), so that the relative amount in the tops will depend upon the nature of the analysed fraction. From the data available it seems that deficiency symptoms may be expected in Dwalganup subterranean clover when the potassium content of either leaf or leaf + petiole falls below 0.8 per cent. It is of interest that this figure agrees substantially with those reported for deficiency in apples (Burrell and Cain, 1941), citrus (Chapman and Brown, 1943), grapevines (Herschler, 1936), and lucerne (Hunter *et al.*, 1943).

Recently, Richards (1944) has stressed the relationship between diagnostic symptoms of potassium deficiency and the relative contents of other ions. He states, *inter alia*, that "it is a characteristic of potassium deficiency that other elements accumulate in the cells," and in reviewing evidence of other workers points out the importance of calcium and magnesium in this regard. His own work with barley clearly demonstrates the importance of sodium also, even in nutrient media high in calcium (Richards and Templeman, 1936).

In the previous paper (*loc. cit.*) evidence was provided that the relative amount of sodium is higher in potassium deficient than in healthy plants, in a medium relatively low in calcium (see Table 2). Even when the supply of calcium is high, the relative amount of calcium in the plant is scarcely affected, while sodium shows a small increase. Magnesium does not appear to play an important role.

Under field conditions, where phosphorus is applied as superphosphate, no sodium is normally provided in the fertilizer. In view of the fact that calcium constitutes about 70 per cent. and magnesium 25 per cent. of the exchangeable cations in the virgin soil, it is of particular interest that a number of analyses have shown no appreciable increase in the relative amounts of either calcium or magnesium in potassium deficient plant samples. The mineral content of the 1945 sample of Table 6 was as follows:—

—		K.	Ca.	Mg.	Na.
		%	%	%	%
(a)	..	0.88	2.04	0.4	0.56
(b)	..	0.44	2.69	0.3	0.97
(c)	..	0.36	1.82	0.3	1.23

Variation in relative amount of calcium is here greater than usual and no explanation can be offered for the high (b) value. The sodium figures, however, show definite increase with decreasing levels of potassium, and are suggestive of a specific response to potassium deficiency in Dwalganup subterranean clover.

5. Discussion

The first factor examined by way of explanation of the differential response of subterranean clover to potassium in the years 1941 and 1942 was rainfall. The Institute records (Table 7) showed that the total quantity of rain during the growing periods was not very different—28.5 in. in 1941 and 29.5 in. in 1942. An important feature of the

1941 season, however, was that almost 18 in. fell in the two months following germination, so that leaching of potassium was to be expected.

TABLE 7.—MONTHLY RAINFALL (IN INCHES) AT INSTITUTE OF AGRICULTURE, PERTH, 1941–1945.

	1941.	1942.	1943.	1944.	1945.
January ..	0·09	0·09	0·95	0·17	0·05
February ..	0·07	0·08	0·49	0·03	0·07
March ..	0·22	2·53	1·01	0·17	0·59
April ..	3·27	2·64	2·53	1·39	0·20
May ..	2·24	5·92	2·33	5·10	4·75
June ..	9·88	9·56	6·09	3·82	13·41
July ..	8·06	4·13	6·07	5·85	5·06
August ..	3·98	5·08	5·89	4·16	9·25
September ..	4·18	1·45	4·04	2·59	3·48
October ..	2·07	2·41	1·06	0·58	0·61
November ..	0·86	0·30	0·24	1·56	1·96
December ..	0·08	1·12	0·00	1·27	0·91
Total ..	35·00	35·31	30·70	26·69	40·34

Results obtained from Experiment 1 (see Table 1) provide no positive evidence for the hypothesis that, in a high rainfall year, excessive leaching might eliminate differences between K and No K treatments. Admittedly, leaching may have taken place in the above trial, but the mean yield for the No K plots was moderately high—15 cwt. per acre of clover—and, in addition, no acute potassium deficiency symptoms were observed at any stage. Furthermore, the main trial extended over 1944 and 1945, two years of abnormally low and high rainfall respectively. Potassium responses were of the same order of magnitude in each season, and even though the second year results were partly dependent upon the first, the fact that rainfall was very high in the second season should, if the hypothesis were correct, have reduced the magnitude of the response to potassium. Already, evidence has been given which might account for the lack of response to potassium in Experiment 2. Leaching losses under field conditions at the Institute may, therefore, be rather less than expected on general grounds; Peech (1941), for instance, has stated that potassium is subject to rapid leaching in sandy soils, independent of pH.

One observation bearing directly on the above question should be mentioned. The author has noted the striking effect of soil cultivation—more particularly, deep cultivation—on the incidence of potassium deficiency symptoms; invariably, these appear after cultivation, whilst adjacent non-cultivated areas remain almost free of symptoms. The reason is not known, but it is suggested that cultivation leads to mineralization of organic matter with release of potassium, which is subsequently subject to considerable leaching

losses. In the equilibrium equations: non-exchangeable K $\overset{\text{I}}{\rightleftharpoons}$ exchangeable K $\overset{\text{II}}{\rightleftharpoons}$ K in soil solution (Peech and Bradfield, 1943), loss of organic matter would enable II to proceed to the right and

also arrest I in the same direction. The possibility cannot be overlooked that the cultivation treatments in Experiment 4 may have been responsible for revealing differences due to potassium which were not evident in Experiment 2.

A point of no small technical interest has to do with the development of symptoms in acute potassium deficiency of subterranean clover. In the older chlorotic leaves marginal scorching and premature senescence is undoubtedly associated with high succulence, although not a direct result of it. This succulence, also, is in all probability a consequence of low carbohydrate level, but the increase in relative amount of sodium may play some part as suggested by the work of Richards and Shih (1940). From work so far conducted at the Institute, it is clear that the "first" stage of potassium deficiency, as characterized by Wall (1939) for the tomato plant, viz., retardation of growth, hard type of plant, accompanied by chlorosis and mottling of the upper leaves and accumulation of carbohydrates, does not occur in subterranean clover. From Wall's tentative explanation (p. 153) it is possible that light intensity and winter temperatures at the Institute were not sufficiently low for this stage.

The later stage of deficiency in subterranean clover wherein leaf-size is greatly reduced can scarcely be assigned to potassium *per se*, and is of interest in relation to nitrogen metabolism. Even though tillering rate and leaf number are not seriously affected by potassium deficiency in subterranean clover, this reduction in leaf-size is suggestive of a direct role of potassium in nitrogen metabolism as indicated by Wall (1940) and others. It is necessary to bear in mind that the absence of effect on rate of leaf production and tillering in the above instance may be directly related to a specific effect of high sodium concentrations (see Gregory, 1937).

Of the plants so far studied—Dwalganup and Mt. Barker subterranean clover, W.A. blue lupin, Wimmera ryegrass, perennial veldt grass, and capeweed—only the clover has shown marked and significant responses to potassium. This is in general agreement with the statement of Bayer (1943) that legumes respond more readily than grasses. The fact that lupins grew satisfactorily without potash fertilizer may have been due to a genetic characteristic: lupins apparently possess the ability to extract difficultly-available soil potassium (Rathsack and Laufer, 1936).

In conclusion it is pertinent to remark that no data are available with respect to two important practical field problems: (a) the amounts of potassium required and residual effects, and (b) the extent of deficiency areas in the south-west of Western Australia. The first calls for further investigation, the intensity of which will depend to some degree on (b). At present there is a dearth of quantitative evidence on the effects of potassium deficiency on pasture plants in southern Australia generally.

6. Acknowledgments

The author wishes to express his thanks to Mr. E. H. Kipps for the chemical analysis, to Mr. E. A. Cornish, Officer-in-Charge, Section of Biometrics, C.S.I.R., for doing much of the statistical work relating to this paper, and also to Mr. R. F. Williams, Division of Plant Industry, C.S.I.R., for valuable criticism and helpful advice.

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Note on the Hilsch Centrifugal Jet or "Maxwellian Demon"

By R. W. Muncey, B.E.E.*

Summary.

From the meagre details available, a small device, used during the war in Germany for replacing ammonia pre-cooling apparatus in a liquid-air machine, has been constructed, and its operation as a possible means of maintaining reduced temperatures in cold conditioning boxes investigated semi-quantitatively. Temperatures as low as 35 deg. C. below atmospheric have been obtained under a variety of conditions examined, and there appears little doubt of the possible efficacy of the device.

During the war, R. Hilsch in Germany used a small device, since referred to as the Maxwellian Demon, to replace the usual ammonia pre-cooling apparatus in a liquid-air machine (1, 2). This device, illustrated in Figs. 1 and 2, consists of a T-shaped tubular structure with a spiral central cavity. The flow in one arm (the left in Figs. 1 and 2) is controlled by a gate valve—and in the second arm (the right) is constricted by a small centrally-placed orifice. When compressed gas is forced through the central leg of the T, the setting of the gate valve determines the relative proportions and temperatures flowing in the arms. With the valve fully opened, gas at the temperature of the input issues at the left and air is drawn in at the right. When the valve is slowly closed, a stage is reached at which a stream of cold gas flows out at the right and that issuing from the left is correspondingly warmed. Further closing of the valve causes a greater decrease in the temperature of the gas issuing at the right until a maximum effect is attained and, beyond this point, the cooling decreases until all the gas issues at the right.

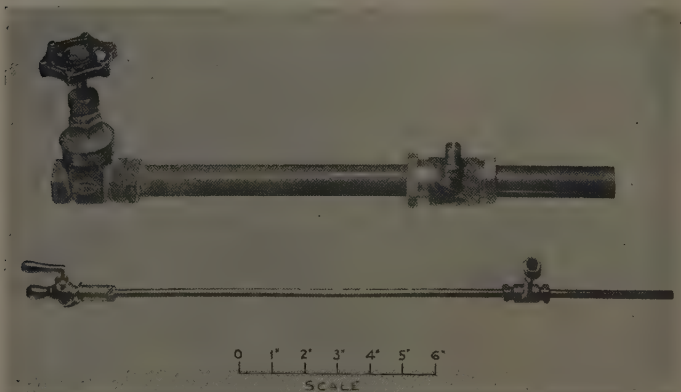


FIG. 1.—Photograph showing the relative sizes of the two Hilsch Centrifugal Jets constructed.

* An officer of the Building Materials Research Section, C.S.I.R.

Apart from the very brief description of the unit itself given in the May and December issues of the Industrial Edition of *Industrial and Engineering Chemistry* for 1946 (1, 2), no definite information on its operation or performance or on the theory behind its operation, has yet become available. However, since the problem of maintaining reduced temperatures in cold conditioning boxes is a major problem in the Building Materials Research Laboratory, it was decided that the device was worth local investigation. Based, therefore, upon the meagre details available, two units of widely differing sizes were constructed in the laboratory workshop and their undoubted success has already indicated the possibility of the device as a refrigerating agent. While the results so far to hand are admittedly only of a semi-quantitative nature, they are considered of sufficient value to pass on to others who may be interested in the utilization of the unit.

LETTERS	A	B	C	D	E	F	G	H	J
SMALL JET	3.90	4.43	.062	.250	.187	.156	.109	.062	.046
LARGE JET	11.62	5.125	.250	1.00	.890	.593	.375	.500	.187

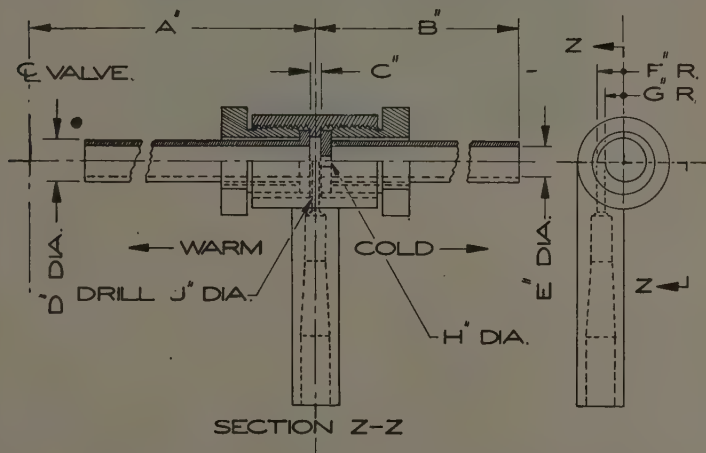


FIG. 2.—Hilsch centrifugal jet (Maxwellian Demon).

The spiral used in the unit is illustrated in Fig. 3 and is approximately of the form $r = a - b\theta^2$ (where r and θ are the polar co-ordinates of points on the curve), the constants being arranged so that a is the required maximum radius and $b(2\pi)^2$ is equal to the inlet jet diameter. This spiral is uniform in a direction along the axis of the arms of the T, and its width in that direction is slightly greater than the diameter of the jet. Its shape can readily be seen in Fig. 3. The jet is formed so that it is perpendicular to the radius vector at $\theta = 0$ and $\theta = 2\pi$ and its axis is distant $a - 2b\pi^2$ from the origin for the spiral. Other relevant dimensions of the two units constructed are shown in Fig. 2.

For the smaller unit the dimensions adopted were approximately those of the German model. This unit proved immediately successful in its trial operations. Compressed air at 90 lb. per sq. in. was used, and air noticeably colder than the surrounding atmosphere issued from the right arm of the demon when the compressed air was turned on and the gate valve adjusted roughly. Further adjustment of the valve indicated that a minimum temperature, about 35 deg. C. below atmospheric, was reached at one particular setting of the valve which eventually proved to be that at which 35 per cent. of the total air introduced was issuing through the cold jet. The maximum cooling effect, however, was reached when the volumes of air issuing at the



FIG. 3.—The spiral cavity of the large unit.

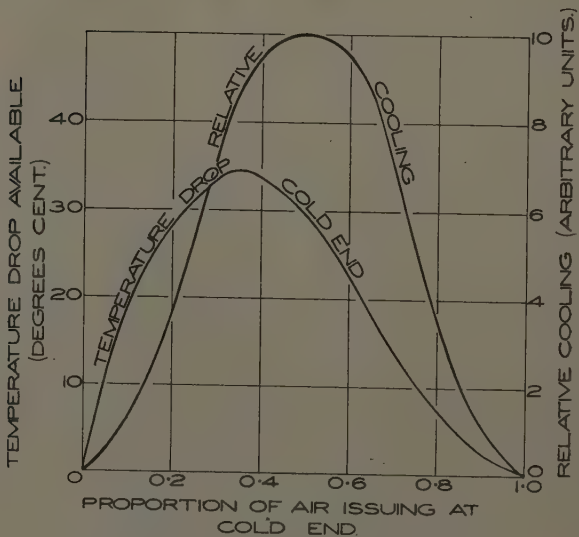


FIG. 4.—Effect of alteration of valve setting.

arms were equal and while changes in the setting of the valve necessarily resulted in corresponding alterations in the relative proportions and temperatures of air issuing from the hot and cold ends, the total flow remained reasonably constant at approximately 800 ml. per second at the pressure of 90 lb. per sq. in. The effective temperature drop in the air issuing from the cold jet, corresponding to a complete range in valve settings from open to shut, with the compressed air at 90 lb. per sq. in. is shown idealistically in Fig. 4.

Reduction of input pressure reduced the temperature drop of the cold air materially, but it was found that the setting of the valve for maximum drop remained constant. The progressive drop in temperature corresponding to compressed air inlet pressures from 0 to 100 lb. per sq. in. is illustrated in Fig. 5. No attempt has yet been made to measure the temperature drop with pressures higher than 100 lb. per sq. in., but icing up of the output tube was seen to occur far more rapidly with a pressure of about 1,000 lb. per sq. in.

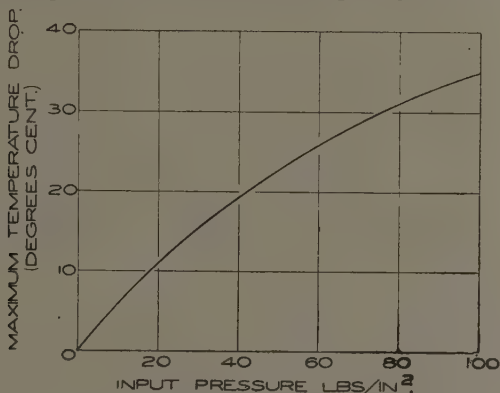


FIG. 5.—Effect of change of pressure upon temperature drop. (Optimum valve setting remained constant.)

Since for practical refrigeration purposes, much longer lengths of tubing through which to pass the cold air would be required, trials were carried out to determine the effect of change of length and of bending and coiling of the output tubes. Alteration of the lengths of both the hot and cold arms from 2 in. to 48 in. had no effect on the maximum temperature reduction of the cold air stream or on the setting of the valve. Bending or coiling of the tubes was similarly without any noticeable effect.

The second model constructed was considerably larger than the first, with the internal dimensions approximately four times those of the former; the relative sizes may be seen in Fig. 1. All tests showed that, within the limits of experimental error, the temperatures available were identical with those obtained with the smaller instrument.

From theoretical considerations in one of the articles describing the original centrifugal jet (2), it seemed likely that a reduction in the size of the cold output orifice should increase the drop in temperature of the cold air stream. Using the larger model for convenience,

the effect of varying the dimensions of the cold orifice was investigated, but it was found (as may be seen from Fig. 6) that, as the diameter of the cold outlet was either decreased or increased relative to that of the warm orifice, the temperature drop diminished in both cases. It is apparent, therefore, that the cold opening used in the original Hilsch jet is about the optimum.*

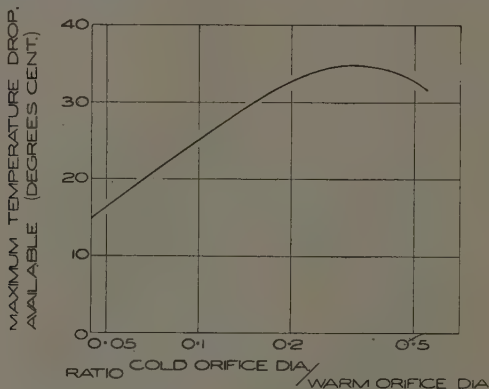


FIG. 6.—Effect of variation of cold orifice diameter on temperature drop. (Valve setting required adjustment for each new orifice diameter.)

While no suitable theory has been evolved to explain the operation of the Hilsch Centrifugal Jet or "Maxwellian Demon," the operation of the units constructed in the Building Materials Research Laboratories indicates clearly that such units show promise of being used to maintain temperatures below atmospheric, in constant-temperature boxes. For design purposes, it is clear that proportional alterations in the size of the jet units and increases in the lengths of the arms will not affect the results obtainable, and it is now proposed to make a number of these jets for use on a practical scale in these laboratories.

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NOTE.—Since the writing of the above article, a further reference has been noted, viz., R. Hilsch (1947).—*Rev. Sci. Instrum.* 18: 108 (Feb.).

Note on Probable Ionization by the Giacobinid Meteor Shower

By G. de V. Gipps, B.Sc.*

Summary.

A description is given of the effect of the Giacobinid meteor shower of October 10, 1946, on the ionosphere as shown on normal ionospheric h',f records. The possibility of meteorites being responsible for ordinary E_s ionization is considered.

No special measures had been taken to observe possible ionization by this meteor shower on October 10, 1946, but subsequent examination of the h',f records of the ionospheric recorder showed ionization below the normal E -layer at that time.

The occurrence of E_s at Brisbane is a minimum in September and relatively little occurs during the early part of October, thus any ionization caused by a meteor shower probably would not be complicated by the presence of ordinary E_s ionization. The maximum of the shower is reported to have occurred at about 1345 hours, 150 East meridian time (1, 2) and consequently would not be seen visually. Two examples of the records obtained are given: Plate 4, Fig. 1, is the record at 1300 hours on which the first indication (isolated spots) of unusual ionization is visible. From 1330 to 1430 hours the echoes were heavy and continuous as shown in Plate 4, Fig. 2, at 1430 hours. After this the effects became weaker and finally disappeared at about 1630 hours.

The equipment used is an automatic h',f recorder with a frequency sweep of 2.2 to 12.5 Mc/s. in 2½ minutes. The peak power output is about 200 watts and the radiation pattern of the "Berkner" (dipole) aeriels varies with frequency. Every sixth sweep is recorded photographically.

From examination of the film the chief characteristics were—

- (1) The abnormal echoes were generally weak.
- (2) There was no indication of blanketing, i.e. the ionization was transparent and the normal ionospheric layers were seen through it.
- (3) With few exceptions the echo heights were well defined: echoes from three different apparent heights were resolved in one case (1330 hours) and preserved their identity for at least 1½ minutes.
- (4) Before and after the maximum, isolated echoes were recorded, possibly corresponding to single meteors.
- (5) There was no marked change in absorption during the period of the shower.
- (6) Examination of records for preceding and following days did not reveal any similar ionization, although occasional transient echoes were recorded.

* A member of the staff of the Physics Department of the University of Queensland, working in co-operation with the Council's Radio Research Board.

From the characteristics of the echoes received, it is concluded that the radio waves were returned by a process of scattering from an area of low but irregular ionization density. If a high ionization density had occurred below the *E*-region the absorption of low frequency radio waves would have increased very considerably. The records are not suitable for accurate height measurement but by using all available information from the film the strongest echoes seem to have been in the range 100 to 110 km. Some echoes had apparent heights up to 180 km. but these would probably be oblique ranges.

Since it took an abnormally intense shower of meteors to produce a weak ionization it is hardly likely that meteors play an important part in the direct production of *Es* though they may supply material (e.g. sodium) which under the ionizing influence of the sun affects the *D*-region absorption (3).

Acknowledgment

This information has been obtained from records of the ionospheric recorder operated by the Physics Department of the University of Queensland in conjunction with the Radio Research Board of the Council for Scientific and Industrial Research and is published with the permission of the latter body.

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Mineral Chlorination Studies

4. The Beneficiation of Australian Graphite by Treatment with Chlorine at High Temperatures

*By F. K. McTaggart, M.Sc.**

Summary.

Graphite schist from the deposits at Uley and Koppio, South Australia, contains widely varying amounts of carbon which may be concentrated by flotation followed by leaching with dilute mineral acid to approximately 90 per cent. carbon. The removal of the residual mineral contaminants from such concentrates has hitherto presented a difficult problem solved only by the use of hydrofluoric acid. This paper describes the chlorination of a flotation concentrate in a tube furnace at temperatures between 1250° and 1450°C., resulting in a product having an ash content of only 0.05 per cent. The influence of temperature, chlorine rate, addition of inert gas, and the effects of carbon tetrachloride were determined.

Graphite having an ash content of 0.5 per cent. was produced using 1 lb. of chlorine per pound of graphite recovered, while with the use of 2 lb. chlorine per pound, graphite containing 0.05 per cent. or less ash was produced.

1. Introduction

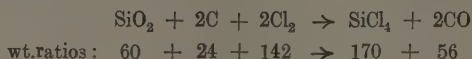
The graphite schist that occurs in the deposits at Uley and Koppio, South Australia, contains widely varying amounts of carbon, together with silica, ferric and aluminium oxides, calcium carbonate, &c. The samples supplied for use in this work contained 15–20 per cent. carbon. Investigational work on suitable ore-dressing methods for such ores has been done by Blaskett and Gartrell(1), Dunkin and Hart(2), and Plante(3) who have shown that concentrates containing 80–90 per cent. of carbon together with 1–5 per cent. of calcite may be obtained after several flotations provided preliminary grinding is carried far enough to liberate associated gangue. Croft(6) has shown that these, and also the lower grades of flotation concentrates (60–70 per cent. carbon) which tend to be produced when efforts are made to preserve the coarse flakes of the ore, can be freed of all gangue except silica by means of a reducing roast following by digestion with dilute sulphuric or hydrochloric acid. Thus graphite can be obtained either by flotation alone or by flotation followed by acid digestion, containing not more than 10–15 per cent. of gangue minerals most of which is either quartz or finely divided silica resulting from the decomposition of silicates. Leaching with hydrofluoric acid has, to date, proved the only effective method for removing this silica and so producing a high-grade graphite.

It is well known that chlorine attacks silica in the presence of carbon at high temperatures giving silicon tetrachloride. Under such conditions compounds of iron and aluminium are also attacked

* An officer of the Division of Industrial Chemistry.

readily, yielding volatile chlorides. There appeared no reason why this method should not be used for the beneficiation of graphite containing impurities such as these, the chief difficulty being in connexion with the use of chlorine at 1200°C. or higher and the finding of a material suitable for the fabrication of a furnace and capable of withstanding chlorine at such temperatures.

The reaction between silica and chlorine in the presence of carbon is as follows:—



There will be some loss of carbon from the graphite owing to the formation of carbon monoxide. The magnitude of this loss will depend on the quantity of impurity to be eliminated, and in the case of a flotation concentrate such as has been described above should not amount to more than 5 per cent. There is no need for a discussion of the thermodynamics of the reaction because of the small amount of silica in the graphite. It was realized from the data available in the literature(4) that temperatures above 1200°C. would be necessary for a rapid removal of the crystalline silica, and provided the amount of chlorine used was not so great as to be excessively costly, the efficiency based on the chlorine would not need to be high.

It was, therefore, decided to determine—

- (i) the optimum temperature for the reaction,
- (ii) the optimum rate of introduction of chlorine,
- (iii) the effect of an inert gas mixed with the chlorine for sweeping out of reaction products,
- (iv) the effect of substitution of carbon tetrachloride for a certain amount of the chlorine,
- (v) the quantity of chlorine necessary to reduce the mineral impurity to approximately 0.5 per cent. and thereafter to approximately 0.05 per cent., and finally
- (vi) to find a suitable material for the construction of the furnace and to develop a satisfactory technique for carrying out the reaction.

2. Raw Materials

In early exploratory experimental work a sample of Uley graphite concentrate leached free from calcite and containing 30 per cent. ash was used. This was chosen in order to determine the general characteristics of the reaction and the likelihood of removing fairly large quantities of contaminants. This was placed in a large vertical silica tube furnace and chlorinated at 800–900°C. for two hours. The oxides of iron and aluminium were rapidly attacked and were almost completely eliminated in that time. The residual graphite contained 15.8 per cent. ash of a light-grey colour consisting almost wholly of silica.

For the later work a further sample of Uley flotation concentrate containing 12.2 per cent. ash was used. It occurred in flake form and had the following screen analysis—

				Per cent.
(a)	+ 48 mesh	..	..	38.4
	+100 mesh	..	..	42.6
	+150 mesh	..	..	10.0
	+200 mesh	..	..	5.0
	—200 mesh	..	..	4.0
				100.0

A quantity of this material was ground in a jar mill to the following size:—

				Per cent.
(b)	+ 48 mesh	..	..	0.2
	+ 65 mesh	..	..	2.5
	+100 mesh	..	..	8.9
	+150 mesh	..	..	17.3
	+200 mesh	..	..	18.8
	—200 mesh	..	..	52.3
				100.0

and a further quantity was ground in the same manner to 85 per cent. minus 200 mesh (c). These three samples were leached in 5 per cent. hydrochloric acid to remove calcite and were then filtered, washed, and dried. The ash content in each case was 8.9 per cent., comprising 6.4 per cent. SiO_2 and 2.5 per cent. R_2O_3 .

3. Experimental

(i) *Using Platinum-wound Furnace.*

In the exploratory experiments the graphite charge was heated in the vertical alundum tube furnace shown in Fig. 1A. This furnace was wound with 26-gauge "platinum — 20 per cent. rhodium" wire and insulated by means of a layer of aluminium oxide and kieselguhr bricks. The various holders used for the charge are shown in Fig. 1A. B, and C. The first three chlorinations, Nos. 4, 5, and 7 in Table 1, were carried out in the silica tube shown inside the furnace in Fig. 1A. The charge was placed in the upper section and the height of the tube was adjusted so that the charge occupied the hottest zone of the furnace. The tube was then luted at the bottom. Chlorine was passed up the centre tube into the charge and nitrogen was passed in between the tube and the furnace walls. The nitrogen served to sweep the excess chlorine and the fumes away at the top of the charge. The wall temperature was recorded by means of a platinum-rhodium thermocouple placed between the silica tube and the furnace wall and readings so obtained were correlated with the temperature at the centre of the charge by means of previous comparisons made with a thermocouple inserted in a charge, without chlorine passing. Forty grams of graphite was found to fill the tube conveniently. It was clear from these three experiments that a temperature of at

least 1250°C. was necessary to bring about a rapid removal of ash. 1300°C. appeared to be desirable because in No. 7 a sample of graphite selected from the centre of the tube was found to have an ash content of 0.1 per cent. The mean ash content of the graphite from this experiment was, however, 0.7 per cent., due almost entirely to silica flakes from the walls of the containing tube. It was obvious, therefore, that silica was unsuitable for the purpose, and attention was turned to graphite. A piece of Acheson graphite electrode (approx. 1.0 per cent. ash) was turned to the shape shown in Fig. 1B. This replaced the silica tube of Fig. 2A. Results from it were disappointing. A typical experiment, No. 8, is shown in the table. The relatively high ash content after prolonged chlorination was due to the rapid conduction of heat away from the charge by the massive lower section of the holder which projected from the bottom of the furnace. It is doubtful whether the temperature of the charge exceeded 1100°C.

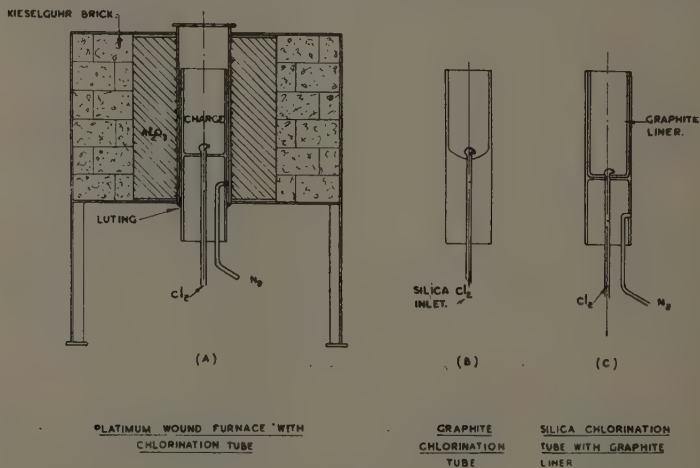


FIG. 1.

TABLE 1.

Experiment No.	Graphite Contained in—	Charge.		Temperature.		Chlorine Used.	Time.	Residue Ash.	Remarks.
		Wt.	Ash.	Wall.	Charge.				
		g.	%	° C.	° C.		hrs.	%	
4	Silica tube ..	40	15.8	..	1,250	..	8	1.7	..
5	Silica tube ..	40	15.8	..	1,200	..	8	8.1	..
7	Silica tube ..	35	15.8	..	1,320	..	10	0.7	Sample from centre = 0.1% ash
8	Graphite tube	39	15.8	1,350	1,100	180	19	3	Temp. too low
9	Graphite liner	27	15.8	1,350	1,250	210	11.5	0.15	..
10	Graphite liner	30	15.8	1,350	1,250	200	12	0.12	..

To overcome this difficulty a return was made to the silica tube, this time fitted with the graphite liner as shown in Fig. 1c. The liner was 3/32 in. thick and had little effect on the temperature of the charge, but owing to the volume occupied by it the charge had to be reduced to about 30 grams. The results of the chlorinations (experiments Nos. 9 and 10) were encouraging. The ash content dropped to 0.15 and 0.12 per cent. respectively and 88 per cent. of the graphite was recovered in each case. However, the amount of chlorine used was excessive, being seven times the weight of the charge. Also, as in previous experiments, a white incrustation of silica collected on top of the charge and in removing this portion of the graphite was lost. The formation of this silica, which is of extreme fineness, appears to be due to hydrolysis of silicon tetrachloride immediately the vapours cease to be in contact with carbon. The hydrolysis must in turn be due to the presence of water vapour not decomposed in contact with carbon at this high temperature. The phenomenon is in line with past experience in chlorination work(5) and, in this case, the water vapour must arise from water absorbed on the graphite and gradually liberated under the action of the chlorine.

This preliminary work showed that—(a) it was possible to reduce the ash in the graphite to a satisfactory figure, and, (b) that a temperature of 1250°C. or higher was necessary for rapid decomposition of the ash. The disadvantages of the apparatus were:—(a) the chlorine was measured by flowmeter which was not sufficiently accurate to yield reliable data for chlorine consumption; (b) although diluted with nitrogen, the chlorine attacked the alundum furnace; (c) the charge was small; (d) part of the charge lifted and slid between the containing tube and the furnace walls when the chlorine rate was high; (e) there was a considerable temperature gradient between the heating element and the charge due to firstly, the alundum tube, and, secondly, the silica tube. For this reason a maximum temperature (centre of hot zone) of only 1320°C. could be attained. At this temperature the heating element was dangerously hot. It was decided, therefore, to set up a furnace that would overcome these disadvantages and yield reliable data on the factors influencing the reaction.

(ii) Graphite Tube Furnace.

(a) *Apparatus* (see Fig. 2).—The furnace consisted of a tube (A) turned from a length of Acheson graphite electrode (1.0 per cent. of ash). The dimensions were—

Maximum outside diameter	..	..	4 in.
Minimum outside diameter	..	..	2½ in.
Inside diameter	..	..	2 in.
Total length	..	..	30 in.
Length of heating section	..	..	12 in.
Length of enlarged electrodes	..	..	7 in.

The tube was held vertically in a steel box (B) insulated by means of 200 mesh charcoal powder (C) and a double layer of kieselguhr bricks (D). Electrical connexions were made at the ends by means of water-cooled clamping electrodes (E). Bus bars (F) with flexible sections (G) served to connect the furnace to a transformer giving a

maximum of 10 volts at 2,500 amps. The furnace was provided with two alundum inspection tubes (H) through which the maximum temperature, i.e., at the mid point, and the temperature at the top of the charge, could be continuously checked during operation. Also provided was an inlet port (I) through which nitrogen was passed during operation of the furnace. The graphite tube was tapped at the lower end and fitted with a screw-in chlorine inlet tube (J). From (J) a $\frac{1}{4}$ -in. hole extended to the working-in section of the furnace. At the top was a hood (K) fitted with a glass inspection window (L) and vent holes (M). The hood was connected to an exhaust fan. The charge (N) rested on a bed of charcoal of $\frac{3}{8}$ -in. mesh (O), and extended to the position marked (X). The graphite sleeve (P) (see later) came to within 1 inch of the level (X).

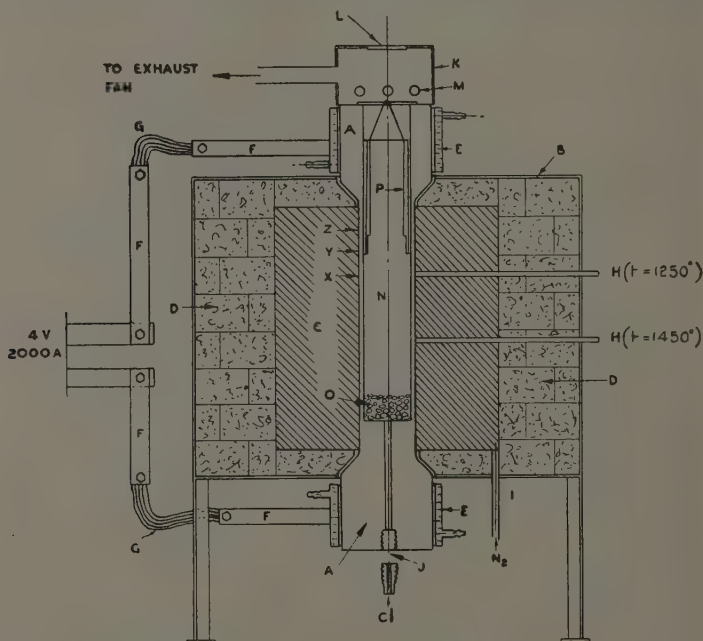


FIG. 2.—Graphite Tube Laboratory Furnace.

The chlorine was supplied from a small cyclinder, 2 inches internal diameter and 12 inches long, made from a length of steel pipe, welded at the bottom and closed at the top with a heavy steel screw-in plug to which was fitted a brass needle valve. This cylinder, which held about 240 g. of chlorine and weighed when full 3.1 kilograms, was filled from a commercial chlorine cylinder by immersing the former in an alcohol-dry ice mixture and allowing chlorine to distil over. Chlorine consumption was determined by weighing the cylinder on Dayton ratio scales accurate to somewhat better than 1 gram. Rates

of chlorine flow were determined roughly by flowmeter and accurately by weighing the cylinder every quarter or half hour during an experiment.

The charge was placed in the furnace with the aid of a funnel and removed by suction into a small bag house. The bag could be weighed accurately for the determination of recovery.

(b) *Calibration of furnace for temperature.*—The furnace was calibrated by means of a platinum-rhodium thermocouple in a thin-walled alundum sheath, inserted down the centre of the tube with a charge of graphite in place. At a mid-point temperature of 1450°C. the temperature at points $3\frac{1}{2}$ inches below and $3\frac{1}{2}$ inches above was 1250°C. This zone was therefore chosen as the working region. The setting of the voltage controls and the voltage across the transformer terminals were noted, and also the temperatures as determined by means of an optical pyrometer through the observation tubes in the side of the furnace. In this way the temperature inside the furnace during an experiment could be estimated. For a maximum temperature of 1450°C. the potential across the furnace was 3.85 volts and the current 1950 amps. In the 7-in. working zone a 70 gram charge could be accommodated.

Initially the charges were chlorinated without the graphite sleeve shown in Fig. 2, but it was found that a layer of oxides formed on the inside wall of the furnace immediately above the top of the charge. These oxides, produced apparently by the reaction discussed previously, then reacted with the graphite wall, resulting in severe pitting. As before, a considerable amount of silica collected in the top layer of the charge and this was removed by suction before the bulk of the graphite was taken out. To prevent pitting of the walls and in order to obviate the waste of the top $\frac{1}{2}$ —1 in. of the charge, several experiments were made using a "topping" of graphite up to the level indicated by (Z). This effectively stopped the pitting but caused difficulty in filling and emptying, because of the tendency for mixing to take place between the charge and the "topping." The problem was finally solved by the use of the graphite sleeve shown in position in Fig. 2. The upper section of this liner was $\frac{3}{16}$ in. thick and the lower $2\frac{1}{2}$ in. was $\frac{1}{16}$ in. thick. Its effect on the temperature distribution was negligible and it was necessary to place only an additional $1\frac{1}{4}$ in. of graphite on top of the charge. This layer was removed with the silica after chlorination. The sleeve was slowly pitted owing to deposition on it of oxides and was replaced from time to time as required.

(c) *Influence of chlorine rate.*—In the experimental work described in this section and in (d) and (e) below, graphite of the type C, i.e., 85 per cent. minus 200 mesh, was used. It was recognized that from the point of view of heating and other operating costs, in an eventual industrial application of the process, the shorter the time of chlorination the better. Hence several experiments were conducted to determine the optimum rate at which chlorine should be passed. The maximum rate practicable was found to be 30g./hr., as at rates faster than this the graphite was carried up the tube by the gas stream. The results cited in Table 2 show that this maximum rate was most effective in bringing about the reduction of the ash. At 30 g./hr. a reduction of ash content from 9 per cent. to approximately

0.5 per cent. was achieved in 2.3 hours, i.e., with a consumption of 70 g. of chlorine (experiments Nos. 19 and 20). When 10 g./hr. of chlorine was passed for 7 hours, again a consumption of 70 g. chlorine, the ash fell to only 4.6 per cent. (experiments Nos. 13 and 14), while at 20 g./hr. an intermediate figure was obtained (experiment No. 18).

TABLE 2.

Ex- peri- ment No.	Charge Wt.	Chlorinating Agent.		Time.	Ash.		Cl ₂ Rate.	Cl ₂ Con- tent of Graph- ite.	Remarks.
		Type.	Amount.		Initial.	Final.			
15	g.			hrs.	%	%	g./hr.	%	
16	70	Cl ₂	70	7	8.9	4.6	10	..	..
	70	Cl ₂ + CCl ₄	70 + 26	7	8.9	4.7	10	..	CCl ₄ added
18	70	Cl ₂	70	3.5	8.9	2.1	20	..	..
19	70	Cl ₂	70	2.3	8.9	0.59	30	0.7	Not gas washed
20	70	Cl ₂	70	2.3	8.9	0.43	30	0.19	Gas washed with N ₂
21	70	Cl ₂	70	2.3	.43	0.02	30	..	..
23	70	Cl ₂	70	2.3	.59	0.05	30	..	..
24	70	Cl ₂	34	3.4	8.9	6.1	10	..	N ₂ sweep 2cc./ min.
25	70	Cl ₂	39	2.6	8.9	2.25	15	..	N ₂ sweep 78 cc./ min.
27	70	Cl ₂ + CCl ₄	47 + 23	2.3	8.9	0.58	20	..	CCl ₄ substituted
29	200	Cl ₂	200	6.6	8.9	3.37	30	..	Flake graphite
30	200	Cl ₂	200	6.6	8.9	3.34	30	..	Flake graphite
31	110	Cl ₂	110	3.6	8.9	2.71	30	..	52%, — 200

(d) *Influence of inert sweeping gas.*—In the elimination of approximately 9 per cent. ash, which corresponds to 6.3 g. silica, not more than 15 g. chlorine would be used, the remaining 55 g. merely serving to sweep away the reaction products. The greater efficacy of the fast chlorine rate appeared to be connected with this rapid removal of products but later it was found to be dependent on another factor also. Graphite containing approximately 0.5 per cent. ash, the product of experiments Nos. 19 and 20, was treated again in the furnace at 30 g./hr. chlorine for 2.3 hours. In one case, No. 21, the ash fell to 0.02 per cent., while in the other, No. 23, it fell to 0.05 per cent. In all these cases the recovery of graphite was better than 90 per cent., based on the graphite (carbon) content of the original sample taken.

Because the greater part of the chlorine appeared to be effective only in sweeping out the reaction products, it was decided to investigate the effect of the substitution of an inert gas such as nitrogen for some of the chlorine. Accordingly experiments were carried out using chlorine 10 g./hr. and equal volume of nitrogen for 3.5 hrs. (Expt. No. 21); and chlorine 15 g./hr. and equal volume of nitrogen for 2.3 hrs. (Expt. No. 25). The results are in no way comparable to the chlorinations in which the whole volume of the gas was chlorine.

This must be due to the fact that the concentration of the chlorine at the graphite-silica surface is reduced by the admixture of nitrogen. The reaction rate thus falls off.

However, the results using chlorine were considered satisfactory. Graphite containing 0.5 per cent. ash could be produced from flotation concentrate by the additional expenditure for chlorine of approximately 4d. per pound of graphite produced plus other operating costs. For a further 4d. per pound a high grade of graphite containing only 0.05–0.02 per cent. ash could be produced. Accurate costing could only be done after pilot plant or large-scale experimental work, but it appears certain that graphites could be produced as cheaply as imported grades.

(e) *Influence of carbon tetrachloride on the chlorination.*—Several experiments were carried out in order to determine the effect on the reaction rate of the addition of carbon tetrachloride. When carbon tetrachloride was passed in large amounts the carbon tetrachloride decomposed and carbon was deposited as a hard tube. Through it the chlorine and carbon tetrachloride were carried up into the middle of the charge and the lower regions were found to contain a relatively large ash. When a portion only of the chlorine was replaced by this reagent as in Expt. No. 27, no carbon tube formed but the results were not significantly different to those obtained from corresponding experiments in which no carbon tetrachloride was present.

(f) *Chlorination of coarser grades of graphite.*—The lamellar structure of graphite suggested that it might be possible to chlorinate the leached concentrate without recourse to fine grinding. However, the experimental data found in Expts. Nos. 29, 30, and 31 showed that, like other minerals studied to date, the graphite must be ground finely for efficient chlorination. The flake graphite (sample A) showed a drop in ash content from 8.9 to 3.35 per cent. (mean of Expts. Nos. 29 and 30) under conditions that brought the ash of the standard graphite (C) to 0.4–0.6 per cent. Graphite B chlorinated more readily and under similar conditions the ash dropped to 1.74 per cent. but the merit of this result is difficult to assess without reliable data on the cost of grinding. It may well be that for some purposes chlorination of graphite of this size would be preferable.

(iii) *Adsorption of Chlorine on Graphite.*

For many purposes such as lubrication, graphite must be free from materials that will cause abrasion, or give rise to corrosion, even under moist conditions such as sometimes obtain in bearings. Samples of graphite from Expt. No. 19, which had been chlorinated to 0.5 per cent. ash and allowed to cool in an atmosphere of chlorine, were analysed for chlorine by the combustion method and found to contain 0.7 per cent. chlorine. If this figure arose from free chlorine the graphite would be quite unsuitable for lubrication. Hence further samples were agitated with 1N sodium hydroxide and with distilled water for 24 hrs., after which the graphite was filtered off and the filtrates tested for chloride with silver nitrate. In each case only the slightest cloudiness was apparent. No attempt was made to estimate the chloride liberated as nephelometric apparatus was not available. At the conclusion of Expt. No. 20 the chlorine was turned off and

nitrogen was passed through the charge at about 50 cc./min. for 0.5 hr. before the temperature was allowed to fall, and thereafter until the charge was cool (about 2 hrs.). The combustion method of analysis showed that there was 0.19 per cent. chlorine present but no trace of chloride could be detected by the other analyses. The chlorine was apparently so firmly bound to the graphite that even prolonged treatment with alkali would not remove it. Croft(6) has thoroughly investigated this property of graphite and the above results are in agreement with his work. It appears, therefore, that graphite prepared by chlorination and gas washed as described would be unlikely to give rise to corrosive compounds under normal conditions.

4. Acknowledgments

The writer wishes to thank Mr. V. A. Bertrand for help in the experimental work; Mr. R. C. Croft for carrying out the determinations of chlorine in graphite by the combustion method and for the preparation and ash analyses of several of the samples in the early stages of the investigations; Dr. A. Walkley and Mr. R. C. Croft for many helpful discussions of the work; and Mr. H. W. Worner for advice concerning the testing of the graphite for corrosive compounds.

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NOTES

Changes of Title of Imperial Agricultural Bureaux

As a result of a recommendation of the 1946 Review Conference of the Imperial Agricultural Bureaux, the Imperial Bureau of Pastures and Forage Crops now becomes the Imperial Bureau of Pastures and Field Crops (Director: Dr. R. O. Whyte). In its expanded form it will cover that part of the literature on the following crops not already the concern of the Bureaux of Plant Breeding and Genetics, or Soil Science; all cereals, field root crops, pulses, groundnuts, cotton and other fibre crops grown on a field scale, sugar beet, and sugar cane, in addition to the literature on grassland management and fodder production which has been the concern of the Bureau for the past seventeen years. Attention will continue to be given to those aspects of plant biological research which refer to the crops now covered and sections will now also deal with farming systems concerned in the production of field or forage crops, and certain economic aspects of crop and fodder production. Although the name of the Bureau has already (as from April 1, 1947) been changed to Pastures and Field Crops, and a second abstracting journal (in addition to *Herbage Abstracts*) is to be published from 1948 onwards, it will be some time before it will be possible to claim that the extended field of research and practice is being adequately covered, or before it will be possible to reply without a little difficulty to inquiries on the new crops now added to the Bureau's responsibilities. It will be much appreciated if research workers, Institutes, and Departments concerned with these crops will send their publications and reports to the Imperial Bureau of Pastures and Field Crops, Penglais, Aberystwyth, Wales, for review in the new abstracting journal dealing with field crops. Particulars of this journal can be sent to persons interested.

Acting on the recommendation of the 1946 Conference the Executive Council of the Bureaux also decided that the Imperial Parasite Service would become the Imperial Bureau of Biological Control as from 1st April, 1947.

Review

"GESTATION PERIODS—A TABLE AND BIBLIOGRAPHY,"

compiled by J. H. Kenneth.

(Technical Communication No. 5 of the Imperial Bureau of Animal Breeding and Genetics, 1946, pp. 30. Price 3s. Obtainable from the Central Sales Branch, Imperial Agricultural Bureaux, Penglais, Aberystwyth, Wales.)

This second edition of a communication first published in 1943 is a source book of information on gestation periods of 300 species, and contains 442 references to literature. The species are arranged in alphabetical order of common names and, in respect to each, all available sources of data are quoted on the mean, maximum, and minimum durations of gestation. For domestic animals, data referring specifically to individual breeds are listed as such.

For most species of animals, in respect to which only limited data are available, indication of the mean gestation period and its range represents the best information which can be obtained. However, abundant data are available for most domestic animals so that a more precise estimate of the normal degree of variation from the mean could be calculated. Maximum and minimum values are of little use except as curiosities, especially when the possibilities of abortion and doubts as to the validity of extremely long records are taken into consideration. For information on the standard deviations of gestation periods in domestic animals, the reader may consult *Animal Breeding Plans* (by J. L. Lush. 1943. Iowa State Coll. Press, Ames, Iowa. 2nd Ed.).

The 300 species listed include various aquatic mammals and Australian marsupials. The data on the human are very numerous and are in two sections, including those records for which the interval from fertilization to labour is measured and those for which the interval used is from last menstruation to labour.

Recent Publications of the Council

Since the last issue of this *Journal*, the following publications of the Council have been issued:—

Bulletin No. 203.—"Agar in Australia," by E. J. Ferguson Wood, B.A., M.Sc.

This Bulletin gives an account of the agar industry in Australia during the war, and the research that led up to it; overseas work on agar is also summarized. The uses of agar, its physical and chemical properties, and methods of testing its various qualities, are discussed, together with the sources of seaweed used as the raw material, and the manufacturing processes employed. The possibilities of the agar industry in Australia are outlined. At the present time the industry produces some 160,000 lb. of agar a year, valued at about £150,000, and it is expanding to the limits of the known beds of the particular type of seaweed required. Much of the agar produced is exported to Britain, the Argentine, and Uruguay.

Bulletin No. 204.—"A Soil Survey of Part of Waterhouse Estate, County of Dorset, North-East Coast, Tasmania," by G. D. Hubble, B.Agr.Sc.

This survey covers an area of 50,000 acres in the Waterhouse Estate lying in the coastal belt north of Scottsdale, north-eastern Tasmania. It was undertaken at the request of the Tasmanian Post-War Land Settlement Committee to examine the soils and estimate the quality of the north-eastern coastal belt for future settlement. The area has been used as sheep and cattle run country for nearly 100 years, but little cultivation has been undertaken and the stock are almost entirely dependent on the natural vegetation.

The soils are of very low fertility for the most part, and on present knowledge it seems unlikely that good pastures could be established economically on them, except in small areas. A limited subdivision of the property into holdings of from 8,000–10,000 acres, each with an initial carrying capacity of about 1,500 sheep, might be possible;

but before any settlement is considered it must be demonstrated that profitable sown pastures can be established. Field trials are being undertaken by the Department of Agriculture for this purpose. The establishment of windbreaks, the prevention of sand drift from the coast, and the provision of adequate drainage, are other problems that must be tackled.

Bulletin No. 207.—"The Fumigation of Wheat in Bag Stacks," by Frank Wilson and F. J. Gay, B.Sc., D.I.C.

Prior to the investigations described in this Bulletin, the effective fumigation of commercial stacks of bagged wheat had never been accomplished, and was generally considered to be impossible of attainment in an economic manner. The stacks to be treated were commonly 100 feet long, 70 feet wide, and about 20 tiers high, and covered by a permanent roof, so the provision of an airtight covering was virtually impossible. Experiments showed that if the stack was built on an airtight base, and airtight curtains were erected round the sides, fumigation could be effectively carried out by applying certain heavier-than-air fumigants over the surface of the stack. Carbon bisulphide at the rate of 1 lb., or methyl bromide at the rate of 2 lb. per 1,000 cubic feet gave a good kill of weevils and mice. The fumigant is not so effective in the top few tiers of wheat, but infestation is largely restricted to the lower part of the stack. This fumigation method, using carbon bisulphide, has been employed extensively in South Australia since May, 1944, and some 4,000,000 bushels of wheat have been treated with entirely satisfactory results.

Bulletin No. 209.—"Interaction of Insect Infestation, Temperature, and Moisture Content in Bulk-Depot Wheat," by Frank Wilson.

This Bulletin describes an experiment in which the changes in insect-densities, temperatures, and wheat moisture contents occurring in bulk-depot wheat inoculated with *Rhizopertha dominica* were studied over a period of ten months. This insect and *Latheticus oryzae* penetrated and bred throughout the zone studied (a depth of 5 feet) during the earlier part of the experiment, but subsequently became restricted increasingly to a shallow surface zone, owing to the development of lethal physical conditions in the wheat. Reproduction near the wheat surface was made possible by lower temperatures and higher moisture contents. Near the surface the loss in wheat weight was as much as 40 per cent., but the percentage rapidly decreased with depth and below a level of about 2 feet the damage was negligible.

Bulletin No. 211.—"The Water Retting of Flax. Résumé of Investigations from 1940 to 1945," by W. L. Greenhill, M.E., and Jean F. Couchman, B.Sc.

The methods now generally adopted for water retting flax are based on a large amount of empirical knowledge in the assimilation and use of which the Belgians have in the past undoubtedly been pre-eminent. The problem as it affected this country has been to adapt Belgian methods to local conditions and straw types and, if possible, improve on them by making retting more of a science than an art. Investigations have been conducted in water retting research both in the laboratory and at commercial plants to determine the effect of varying such factors as the temperature and duration of the

preliminary rinse, the temperature, straw to water ratio, dilution and duration of the ret proper, and the use of a final wash. Single and double retting and special retting techniques, such as the treatment of crated straw in channels, have been tried, and also the influence of such factors as the use of saline water, supplies of which occur naturally in certain of the flax districts. Precise methods for determining rate of progress and the end-point of a ret have been considered and a technique developed which, based on the buffer capacity of the retting liquor, has greatly assisted in making comparisons between different retting schedules.

As the outcome of this work, it has been possible to recommend to flax mills a basically sound retting procedure, which is economical of time, labour, water, and fuel, and can be used with confidence for the type of straw grown in this country.

Bulletin No. 217.—"The Relative Importance of Live Sheep and of Carrion as Breeding Grounds for the Australian Sheep Blowfly *Lucilia cuprina*," by D. F. Waterhouse, M.Sc.

Lucilia cuprina is what is called a primary fly, that is, it is responsible for initiating strikes in sheep. Secondary flies are attracted to struck sheep, but are of little danger to sheep in the absence of primary flies, so control measures should be directed against the latter. Past observations have indicated that strikes in living sheep are responsible for breeding the primary fly, carcasses being far less important, so this was tested in experiments described in the present Bulletin. *Lucilia cuprina* flies developed from only 6 out of 27 carcasses exposed at Canberra at intervals throughout the year, with an average of four flies per animal, whereas an average of 10,000 secondary flies developed from each carcass. On the other hand, an average of over 1,200 *L. cuprina* per strike was produced from 26 struck sheep, and generally no secondary flies at all. Thus, the destruction of carcasses is of no value in controlling primary flies.

Bulletin No. 224.—"Mechanical Composition of Soil in Relation to Field Descriptions of Texture," by T. J. Marshall, M.Agr.Sc., Ph.D.

This Bulletin was reviewed in the last issue of this *Journal* (20: 315).

Forthcoming Publications of the Council

At the present time, the following future publications of the Council are in the press:—

Bulletin No. 202.—"The Strain Complex and Symptom Variability of Tomato Spotted Wilt Virus," by D. O. Norris, M.Sc. (Agric.).

Bulletin No. 206.—"Pedogenesis Following the Dissection of Lateritic Regions in Southern Australia," by C. G. Stephens, M.Sc.

Bulletin No. 210.—"Preliminary Survey of the Natural Pastures of the New England District of New South Wales, and a General Discussion of Their Problems," by R. Roe, B.Sc. (Agric.).

Bulletin No. 212.—"The Frictional Properties of Lead-Base and Tin-Base Bearing Alloys: The Role of the Matrix and the Hard Particles," by D. Tabor, Ph.D.

Bulletin No. 213.—"Laboratory and Field Tests of Mosquito Repellents," by R. N. McCulloch, B.Sc., B.Sc.Agr., and D. F. Waterhouse, M.Sc.

Bulletin No. 214.—"The Preparation and Properties of Synthetic Cryolite," by P. Dixon, M.Sc., and T. R. Scott, M.Sc.

Bulletin No. 215.—"Studies in the Biology of the Skin and Fleece of Sheep. 4. The Hair Follicle Group and its Topographical Variations in the Skin of the Merino Fœtus," by H. B. Carter, B.V.Sc., and Margaret H. Hardy, M.Sc.

Bulletin No. 216.—"An Examination of the Peet-Grady Method for the Evaluation of Household Fly Sprays," by D. F. Waterhouse, M.Sc.

Bulletin No. 218.—"Studies of the Physiology and Toxicology of Blowflies. 12. The Toxicity of DDT as a Contact and Stomach Poison for Larvae of *Lucilia cuprina*. 13. Insectary Tests of Repellents for the Australian Sheep Blowfly," by D. F. Waterhouse, M.Sc.

Bulletin No. 219.—"Spray Tests against Adult Mosquitoes. 1. Laboratory Spray Tests with Culicine (*Culex fatigans*) Adults," by D. F. Waterhouse, M.Sc. "2. Spray Tests with Anopheline (*Anopheles punctulatus farauti*) Adults," by D.F. Waterhouse, M.Sc., and D. O. Atherton, M.Sc.Agr.

Bulletin No. 220.—"The Preparation and Use of Harvey's Reduced Strychnine Reagent in Oceanographical Chemistry," by D. Rochford, B.Sc.

Bulletin No. 221.—"Contributions to the Study of the Cell Wall. 4. The Nature of Intercellular Adhesion in Delignified Tissue. 5. The Occurrence, Structure, and Properties of Certain Cell Wall Deformations," by A. B. Wardrop, M.Sc., and H. E. Dadswell, D.Sc.

Bulletin No. 222.—"The Chaetognatha of South Eastern Australia," by J. M. Thomson, M.Sc.

Bulletin No. 223.—"Report of Marine Borer Survey in New Guinea Waters," by A. W. Shillinglaw, B.Sc., Dip.For., and D. D. Moore, B.Sc., A.S.T.C.

Bulletin No. 225.—"Studies on the Control of Wheat Insects by Dusts. 1. Field Tests of Various Mineral Dusts against Grain Weevils," by F. J. Gay, B.Sc., D.I.C., F. N. Ratcliffe, B.A., and R. N. McCulloch, B.Sc., B.Sc.Agr. "2. Further Tests of Various Mineral Dusts for the Control of Grain Pests," by F. J. Gay, B.Sc., D.I.C. "3. The Use of Dust Barriers for the Control of Grain Insects," by F. J. Gay, B.Sc., D.I.C. "4. The Use of DDT- and 666- impregnated Dusts for the Control of Grain Pests," by F. J. Gay, B.Sc., D.I.C.

Bulletin No. 226.—"An Ecological Study of the Australian Plague Locust (*Chortoicetes terminifera* Walk.) in the Bogan-Macquarie Outbreak Area, N.S.W.," by L. R. Clark, M.Sc.

Bulletin No. 227.—"Studies on Perennial Veldt Grass (*Ehrharta calycina* Sm.)," by R. C. Rossiter, B.Sc.(Agric.).

Bulletin No. 228.—"Ecological Observations on the Small Plague Grasshopper, *Austroicetes cruciata* (Sauss.), in the Trangie District, Central Western New South Wales," by L. R. Clark, M.Sc.

Bulletin No. 229.—"Studies in Cement-Aggregate Reaction. I.—Australian Aggregates and Cements," by A. R. Alderman, D.Sc., Ph.D., A. J. Gaskin, M.Sc., R. H. Jones, B.Sc., and H. E. Vivian, B.Sc.Agr. "II.—The Effect of Alkali Movement in Hardened Mortar," by H. E. Vivian, B.Sc.Agr. "III.—The Effect of Void Space on Mortar Expansion," by H. E. Vivian, B.Sc.Agr. "IV.—The Effect of Expansion of the Tensile Strength of Mortar," by H. E. Vivian, B.Sc.Agr. "V.—The Effect of Void Space on the Tensile Strength Changes of Mortar," by H. E. Vivian, B.Sc.Agr. "VI.—The Effect of Carbon Dioxide," by A. J. Gaskin, M.Sc.

Bulletin No. 230.—"The Preparation and Properties of Aluminium Fluoride," by T. R. Scott, M.Sc.

"The Commercial Timbers of Australia—Their Properties and Uses," by I. H. Boas, M.Sc.

"Handbook of Australian Pelagic Tunicates," by Harold Thompson, M.A., D.Sc.

PLATE 1

The Variation of Tensile Strength and Modulus of Elasticity of Hoop Pine Veneer with the Direction of the Grain. (See page 338.)



FIG. 1.—Test rig for specimens loaded at nominal angles of from $22\frac{1}{2}^{\circ}$ to 55° to the grain.

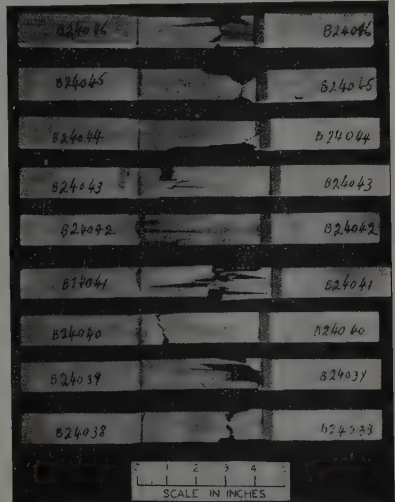


FIG. 2.—Typical failures with the direction of loading parallel to the grain of the veneer.

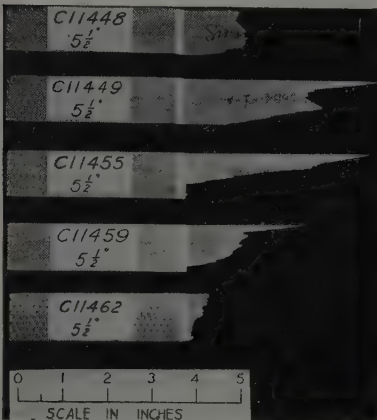


FIG. 3.—Typical failures with the nominal direction of loading at $5\frac{1}{2}^{\circ}$ to the grain of the veneer.

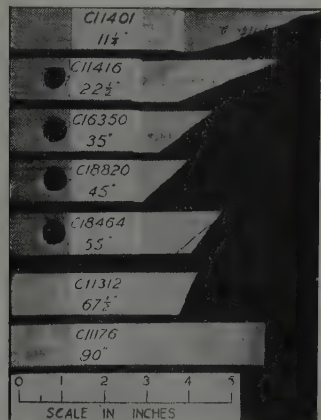


FIG. 4.—Typical failures with the nominal direction of loading at angles of from $11\frac{1}{2}^{\circ}$ to 90° to the grain of the veneer.

PLATE 2

Tests on Small Clear Specimens of North Queensland Kauri.
(See page 345.)



FIG. 1.—Typical fractures of centre-point and four-point bending specimens.



FIG. 2.—Typical failures of specimens tested in compression parallel to grain (large prism).

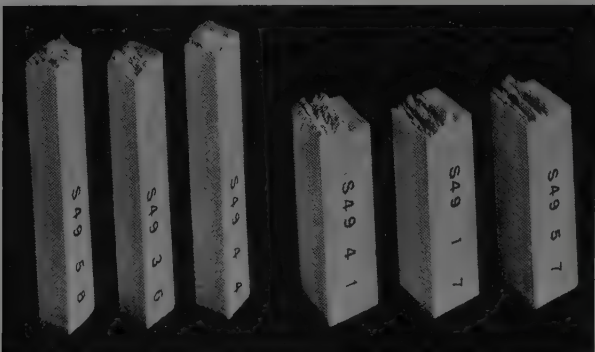
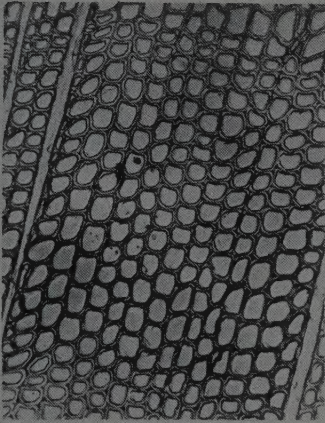


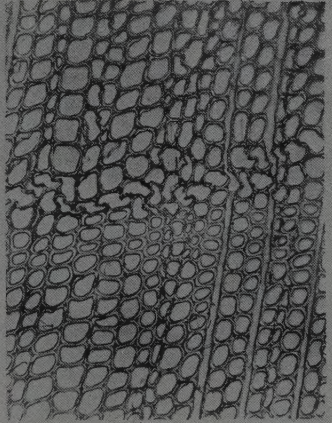
FIG. 3.—Brittle failure of kauri under impact loads illustrated in toughness and Izod fractures.

PLATE 3.

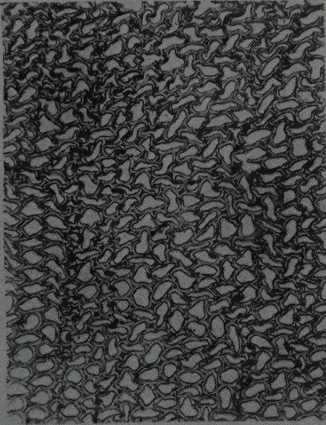
The Nature of Plastic Deformation in Wood at Elevated Temperatures.
(See page 361.)



a.



b.



c.



d.

(a) Showing a specimen without fracture. Pressed at 400 lb./sq. in. and 140°C.

(b) Showing a specimen with incipient cell wall fracture in the early wood. Pressed at 1,000 lb./sq. in. and 160°C.

(c) Showing a specimen with advanced fracture of the cell wall. Pressed at 1,200 lb./sq. in. and 200°C.

(d) Enlargement of part of (c).

PLATE 4

Note on Probable Ionization by the Giacobinid Meteor Shower.
(See page 407.)

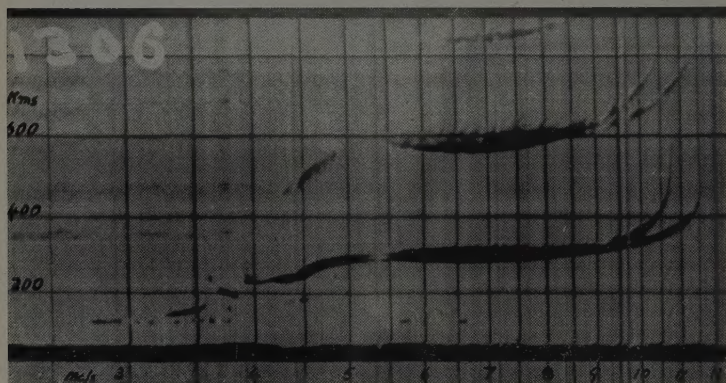


FIG. 1.—The first indications of ionization by the meteor shower occurred on records for 1300 hours on October 10, 1946. The transient echoes are at a height of about 100 km.

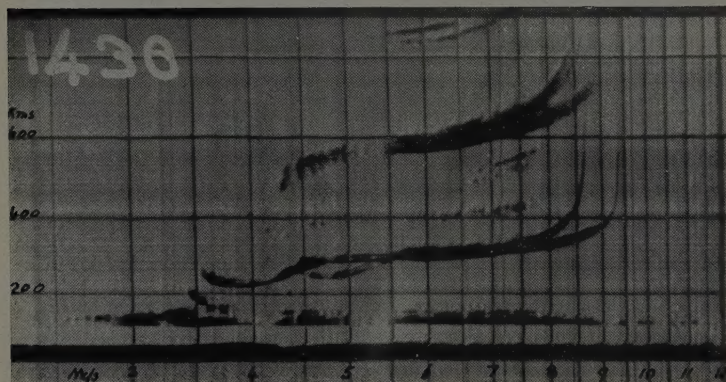


FIG. 2.—At the maximum of shower the records appeared as shown, frequently with well-defined "layers" present above 100 km.

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